A STUDY OF THE DETRITAL HEAVY MINERALS OF WESTLAND

A thesis presented for the degree

of

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by

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FOREWORD AND ACKNOWLEDGMENTS

This thesis presented in the Chemistry Department of the University for the degree of Master of Science describes research in an inter-disciplinary area in which little previous work has been done within New Zealand. Extensive field work and several expeditions have been required, often in very inaccessable country. In addition, the nature of the work has required that I maintain close contact with both the Chemistry and Geology Departments.

Firstly I wish to express sincere thanks to my supervisor, Professor C. Wilkins, for his interest and encouragement throughout this study. I am also indebted to a number of members of the Geology Department, especially the late Dr. Walter Oldershaw and Dr. Douglas Lewis with whom I have had the benefit of helpful discussions and to Mr. David Smale of the Christchurch Office of Geological Survey, particularly for his advice over certain mineral identifications.

I gratefully acknowledge the cheerful willingness of fellow students and friends who accompanied me on field trips and helped with the recovery of often all-too-heavy samples of stream sands from remote spots. For their help with accommodation I wish to express my thanks to my uncle and aunt, Mr. and Mrs. Jim Bradley of Hokitika, and to Alpine Helicopters Ltd., whose provision of air-lifts without charge enabled me to retrieve samples from some of the less accessible areas of South Westland.

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ABSTRACT

The thesis describes a systematic investigation of detrital heavy minerals from the catchment of the Taramakau River, which drains both the Alpine schists and Tuhuan granites. Samples were taken from small feeder streams within source rocks, at various stages down river, from the river mouth and from the beaches to the north and south of the mouth. Information has been gained on persistence characteristics of the minerals and their accumulation in the beachsands.

Within the granites of the Hohonu Range batholith a zone of hydrothermal alteration was discovered. Both stream sediments and X-ray fluorescence analysis of rock samples have shown there is no associated mineralisation, although the original nature and extent of the zone is unknown.

Concentrates from the Kanieri Company's dredge operating in the lower Taramakau have shown that a more complex suite of minerals including cassiterite, monazite, uraninite and thorite lie buried beneath the present river gravels. (This is the first discovery of a significant uraninite deposit in New Zealand).

A survey of beachsands from Hokitika southwards to Milford Sound has shown that those beaches in proximity to the Alpine schist belt contain almost exclusively a very uniform suite of typically schist-derived minerals.

From Jackson Bay southwards where the schists give place to a greater variety of rock-types there is a corresponding change in the heavy mineral suites within the associated beachsands.

While no studies have previously been made specifically on the provenance and accumulation of detrital minerals in this area, the results are discussed in relation to the details of Hutton's (1950) mineralogical investigation of West Coast beachsands and dredge concentrates.

CHAPTER 1

INTRODUCTION

The extensive accumulation of beachsand heavy minerals along the West Coast of the South Island raises questions as to their origin. From the results of detailed mineralogical analysis Hutton (1950) has suggested that there are three mineral provinces within the Westland region, (i) the Grey River Valley where the heavy mineral suites characteristically contain cassiterite, (ii) the region southwards from Hari-Hari where uranothorite but no cassiterite occurs, (iii) the intervening central area covering Taramakau, Arahura and Hokitika catchments where neither cassiterite nor uranothorite were found. However, there appears to have been no systematic extension of this work to identify the contributing sources of the individual beachsand minerals.

Nicholson (1955) carried out an extensive search for uranium and thorium minerals throughout New Zealand over a period of two years. Many of his samples were taken from beachsands, dredge concentrates, river sediments and bore holes at locations on the West Coast of the South Island.

As an initial step the heavy detrital minerals in feeder streams of the Taramakau River catchment in the central Westland region have been examined. This particular area was chosen for several reasons, (i) accessibility, (ii) the widespread occurrence of the two major central Westland rock types, the Alpine schists and

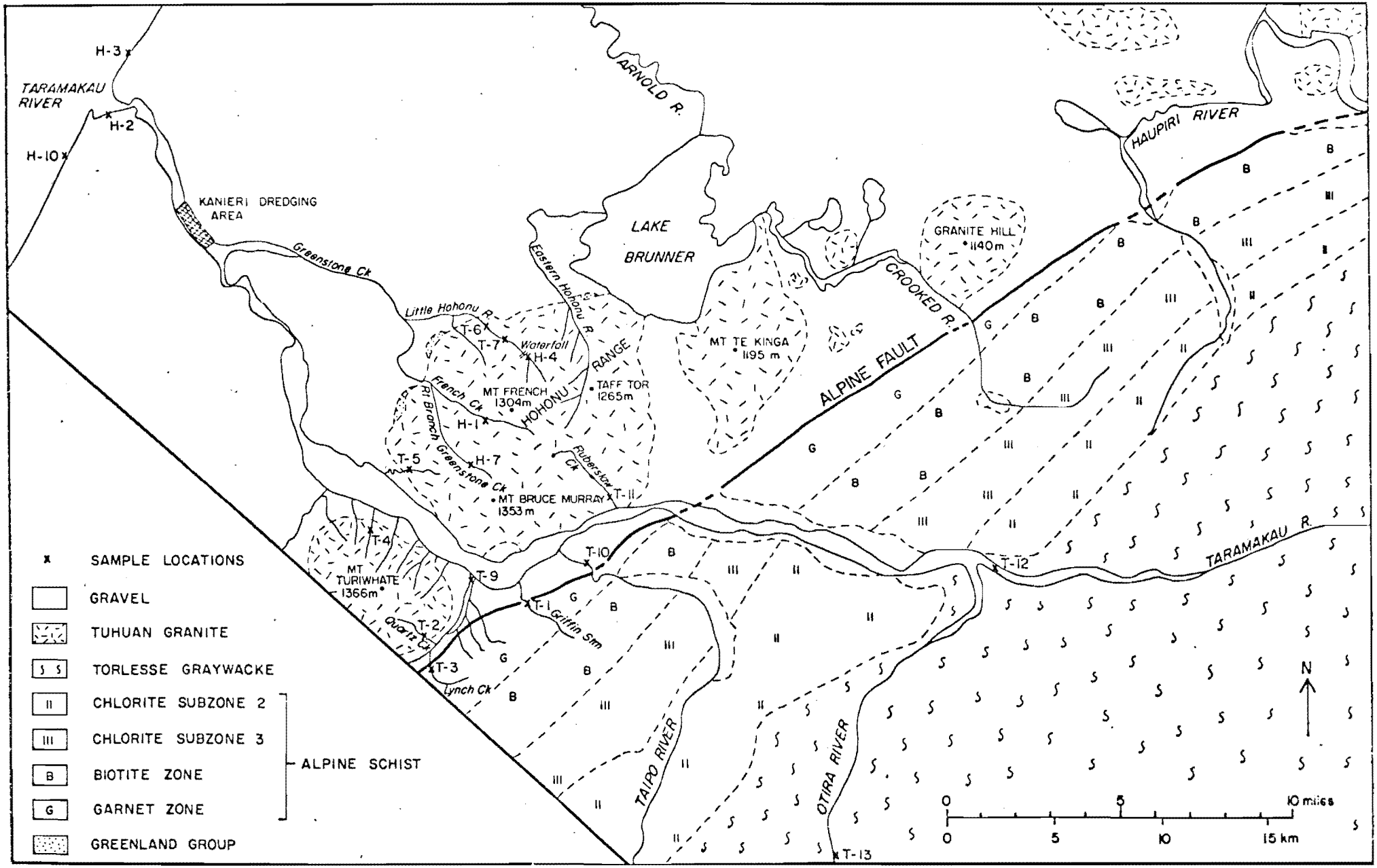
Tuhuan granites, and (iii) the availability of dredge concentrate from the Kanieri Dredging Company's operations in the lower Taramakau River.

A survey of heavy detrital minerals in the beachsands of central and south Westland seemed an appropriate adjunct to the work in the Taramakau region. A northwards longshore drift (Brodie 1960) means that material from the south is contributing to the north Westland beachsands and sample collecting along the beaches is for the most part a less demanding task than high level stream sampling. Consequently a series of beachsand samples taken from Hokitika southwards to Martins Bay (South Westland) were examined for heavy mineral content. The results of these analyses along with those from the Taramakau catchment are presented in the following chapters.

PART I

THE TARAMAKAU RIVER CATCHMENT, CENTRAL WESTLAND REGION.

FIG. 1 : TARAMAKAU RIVER CATCHMENT



CHAPTER 2

DESCRIPTION OF ROCK TYPES WITHIN THE TARAMAKAU CATCHMENT.

The Southern Alps, which form the backbone of the South Island of New Zealand, are composed of the Torlesse graywackes and argillites which merge into the Alpine schists of progressively higher grade westward of the Divide. The schists terminate at the scarp of the Alpine fault, to the west of which again lie a chain of granite plutons and batholiths known collectively as the Tuhuan granites. Late Pleistocene glaciations have left widespread lateral and terminal morainic remnants mainly composed of graywacke - schist rocks and to a lesser extent granitic rocks. These features are well represented in the Taramakau catchment. In addition several small lenses of the Cambrian - Ordivician Greenland group and Tertiary sediments are exposed along the western flanks of the Hohonu range but since the drainage pattern over these outcrops is limited they are not considered to be significant contributions of detritus (Fig. 1).

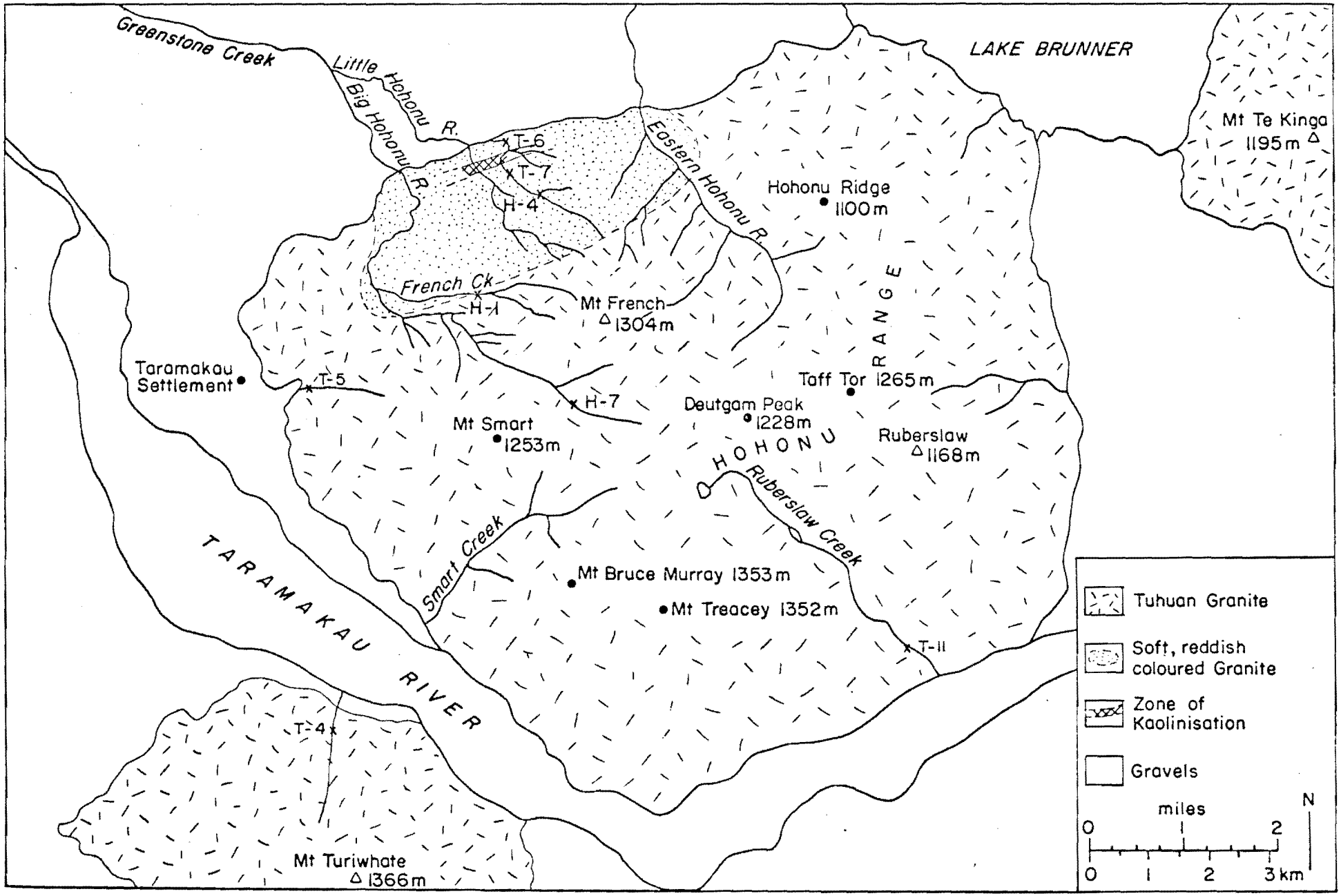
Alpine Schists. The schists rise very steeply from the Alpine fault to a height of 1000-1600 meters. High relief and the comparative ease of denudation of schist probably means that these rocks make a major contribution to the heavy detrital beach accumulates. Both the petrology and history of these rocks have been extensively

investigated by Mason (1962).

Tuhuan Granites. Two large plutons, Mt. Turiwhate and the Hohonu range lie within the confines of the Taramakau watershed. In both cases the granite is predominantly a white hornblende-biotite type with a medium grained texture. However, there are considerable local variations particularly within the Hohonu range (Fig. 2) where the Eastern Hohonu, Big Hohonu and especially the Little Hohonu streams are deeply incised into a softer reddish granite. This commonly shows signs of alteration and in places there are Kaolinised zones indicative of hydrothermal alteration. The upper reaches of the Little Hohonu, (above 50m waterfall), contain occasional boulders of tourmaline granite. Both plutons are intersected with radiating basaltic and lamphophyre dykes.

Because of the variations observed within the granites several rock samples were selected from the Hohonu range and Mt. Turiwhate as well as a few from other Tuhuan granite plutons within the central Westland region. Apart from noticeable variation in texture and proportion of ferro-magnesium constituents there was the question of alteration associated with the hydrothermal zone. Selected samples were subjected to, (i) examination of hand specimens, (ii) petrographic analysis of thin sections with emphasis on the occurrence of heavy, accessory minerals, (iii) analysis of major elements by X-ray Fluorescence Spectroscopy (XRF). Table 2.1 summarises the data obtained from these analyses. It will be seen that in

FIG. 2 ZONE OF HYDROTHERMAL ALTERATION — HOHONU RANGE



terms of major elements (part c) samples 3,4,7,8,9 and 10 are closely similar although the major mineral constituents and the corresponding petrographic classification of the individual samples differs markedly. In particular, despite the fact that the SiO_2 content remains constant over a number of samples the proportion of free quartz fluctuates considerably and a low quartz content is often compensated by a high alkali feldspar content.

Sample 1 which showed abundant apatite [$Ca_5(PO_4)_3(OH,F,C)$] in thin section contains a correspondingly high P_2O_5 percentage (0.38), in fact the highest of the ten samples. The K_2O content (6.05) is also the highest and perhaps predictably this sample contains 80% alkali feldspar [$K(AlSi_3O_8)$]. Both samples 1 and 2 show comparatively high CaO and TiO_2 with a corresponding abundance of the accessory mineral sphene ($CaO.TiO_2.SiO_2$). Sample 3, whose Na_2O content is high, shows a corresponding abundance of plagioclase feldspar [Albite-$Na(AlSi_3O_8)$]. The high H_2O and CO_2 content of sample 5 is reflected in an abundance of the hydrated mineral chlorite which has altered from biotite. From the widespread occurence of biotite in sample 6 the sample has been classified as a biotite gneiss. Sample 8 which is low in MgO is also deficient in the Mg carrying minerals biotite and chlorite.

Table 2:1 shows a well defined correlation between observed petrographic features (parts a and b) and major elemental composition (part c). In fact part (c) suggests that despite wide variations in the petrographic interpretation

of the rock samples the overall elemental composition of these selected Tuhuan granites is remarkably uniform, including those samples taken from the hydrothermally altered zone of the Hohonu range (samples 1, 8, 9 and 10).

(The writer would like to express his thanks to Mr. Glen Coates of the Geology Department, University of Canterbury, for his help with the petrographic analysis and interpretations of these samples.)

Table 2.1

Analysis of Rock Samples

Part (a) Major Constituents

Sample No.	1	2	3	4	5	6	7	8	9	10
Rock Classification	Biotite microline	Hornblende quartz monzanite	Granodiorite	Quartz Monzonite	Granodiorite	Biotite gneiss	Pegmatite	Biotite granite	Biotite granite	Quartz Monzonite
Locality *	French Creek Hohonu Range	Camp Creek Mt. Tuhua	Island Hill	Mt. Tuhua	Mt. Turiwhate	Mt. Turiwhate	Johnson Creek Mt. Tuhua	Big Hohunu River Hohunu Range	Little Hohonu River Hohonu Range	Eastern Hohonu River, Hohonu Range
Average Grain Size	1mm	2mm	1.5mm	0.5mm	2mm	1mm	30mm	2mm	3mm	2mm
Alkali Feldspar (Perthite)								70%	54%	
Alkali Feldspar (Orthoclase)		30%	10%		15%		~60%			21%
Alkali Feldspar (Microcline)	80%			20%						
Plagioclase Feldspar (Albite)	<1%		55%		53%	40%		15%	15%	
Plagioclase Feldspar (Andesine)		40%								
Plagioclase Feldspar (Albite/Oligoclase)				40%						30%
Quartz	17%	20%	30%	35%	20%	40%	40%	12%	25%	40%
Accessory Minerals (part (b))	~2%	~10%	~5%	~5%	~12%	~20%	<1%	~3%	~6%	~9%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

* For further reference see Figs. 1 and 17 .

Table 2:1 (cont.)

Part (b) "Heavy" (accessory) Minerals.

Sample No.	1	2	3	4	5	6	7	8	9	10	PETROGRAPHIC ANALYSIS
Apatite	VA	A	C	S	C	VA		R	S		
Biotite	VA					VA		A	C	C	
Chlorite		C	S	R	A			S		C	
Hornblende		A									
Magnetite	S	S	C	S	C	R		R	S	R	
Muscovite			R	S							
Sphene	VA	A	S	S	R	R		R	S		
Zircon	S				R	R		A	S		

Key A = abundant; C = common, S = sparse; R = rare; VA = very abundant.

Abundances given here are based on a comparative scale for these rocks only, the values being relative for each individual mineral species. These abundances have been estimated by the eye using the Colorado School of Mines classification system. In most cases, with the exception of biotite and hornblende, the proportion of heavy minerals in a thin section seldom exceeds 3%.

Table 2:1 (cont.)

Part (c) Chemical Analysis for Major Elements (percent. of total rock).

Sample No.	1	2	3	4	5	6	7	8	9	10	X-RAY FLUORESCENCE ANALYSIS
SiO_2	61.06	65.91	73.74	75.47	64.36	67.92	73.30	74.47	76.05	75.72	
TiO_2	0.93	0.68	0.28	0.21	0.66	0.66	0.39	0.24	0.20	0.25	
Al_2O_3	16.81	14.75	13.55	13.10	13.83	15.35	13.24	12.36	12.25	12.41	
Fe_2O_3	0.24	1.65	0.64	0.61	1.28	0.43	1.66	0.59	0.75	0.52	
FeO	5.00	2.40	0.86	0.57	3.00	3.60	0.29	1.30	1.15	1.00	
MnO	0.14	0.12	0.02	0.07	0.08	0.11	0.01	0.05	tc	0.06	
MgO	2.23	2.24	0.64	0.26	2.17	1.76	0.24	0.15	0.25	0.66	
CaO	2.98	3.65	0.58	0.95	2.44	3.82	0.04	0.81	0.19	0.66	
Na_2O	3.01	3.50	4.10	3.20	2.60	2.60	6.38	3.80	3.00	2.95	
K_2O	6.05	3.45	3.84	3.77	4.13	1.96	3.10	4.78	5.00	4.45	
P_2O_5	0.38	0.28	0.11	0.13	0.25	0.18	0.14	0.08	0.12	0.06	
CO_2					1.6						
H_2O +	0.67	1.36	1.30	1.40	3.2	1.29	1.10	0.92	0.59	0.92	
Total	99.5	99.99	99.66	99.74	99.60	99.68	99.89	99.55	99.55	99.66	

tc = trace

CHAPTER 3

COLLECTION AND PROCESSING OF SAMPLES

(1) Field Collection. In order to minimise uncertainty over the source of the minerals most of the inland sampling locations were chosen in the headwaters of streams well above any extraneous morainic debris. In the Hohonu range where the catchments were larger than in the other granite plutons samples were taken in the headwaters of small feeder streams as well as from downstream sites.

Sediment shovelled from a stream bed was then passed through a field sieve and the heavies concentrated by panning. The sieve mesh chosen was 0.0ϕ (1000 microns), 0.5ϕ (750 microns) or 1.0ϕ (500 microns) depending on proportion of fine sand available (Appendix 1). The proportion of fine sand was lower when stream gradient was high and 'normal' water flow small. Stream sediments from granites were coarser than from schists and a 0.0ϕ sieve was normally used. However the proportion of heavy minerals in the finer fractions from granite sand was generally high (~ 20%) whereas the schist sands contained less than 5%. The weight of sample collected was usually about 5.5 kilograms (Table 3:1).

Plate 1.

Collecting sample - Eastern Hohonu River

Plate 2.

Panning for heavy minerals - Right branch of Greenstone Creek, (Sample H-7).

(2) Laboratory Processing

Samples were oven-dried, weighed and cut into 1.0ϕ, 2.0ϕ, 3.0ϕ, 4.0ϕ and <4ϕ sieve fractions. While in principle it would have been desirable to float all sieve fractions those coarser then 3.0ϕ tended to contain increasing proportions of inclusions which complicated subsequent magnetic separation. Attention was therefore concentrated on the 3ϕ and 4ϕ cuts but from time to time coarser fractions were checked to ensure there were no undetected differences in the mineral assemblages.

Following flotation in tetrabromoethane, magnetite was removed from the heavy minerals by hand magnet. The remaining concentrate was then passed through a Franz Isodynamic Separator at the following successive settings; 0.2, 0.35, 0.45, 0.75, 1.2 amps using 8^{o} side slope and 15^{o} forward tilt (Table 3:1).[1] *

Depending upon sufficiently large differences in density, (at least a difference of 1 to 1.5 in specific gravity), it was possible by use of a superpanner to effect the concentration and sometimes complete separation of the minerals within individual magnetic cuts. However, the most reliable means of ensuring complete separation was by hand-picking under a binocular microscope using a fine paintbrush (Fig.10). Although this latter technique was tedious, small quantities of a given mineral could be efficiently isolated for subsequent analysis.

* see page 136

Fig. 3

Standard Sample Processing Sheet.

Date: 12.1.77

1. Sample No: H-1 Locality: French Creek Map reference: NZMS 50151
2. Weight of sample floated: 291.3 gm. (total 4.0ϕ)
3. Weight of heavy minerals: 86.15 gm
4. Percentage yield: 27.86

Comments:

5. Weight of size fractions (gm)

0.0ϕ	1.0ϕ	2.0ϕ	3.0ϕ	4.0ϕ	<4.0ϕ
—	—	1708	1397	291.3	54.8

6. Size fraction selected for analysis 4.0ϕ
7. Weight of magnetic cuts. (gm)

Magnetite	0.2amps	0.35amps	0.45amps	0.75amps	1.2 amps
33.097	6.013	15.767	13.563	4.331	3.221

Rejects 5.160

8. Radioactivity T= 1.2 min Background= 12

Magnetite	0.2amps	0.35amps	0.45amps	0.75amps	1.2amps
18	21	17	21	38	49

Rejects 77

9. Composition of Magnetic Cuts (See Table 5:1)

Rejects ZZ, S, FE, PP.

1.2amps SS, P, F, Pu*

0.75amps EE, D, L, ss, cl.

0.45amps HH, E, cc.

0.35amps HH, B, $.

0.2 amps II, H, B, $.

Comments.
1.2 amps - intense blue coloured grains, Optical examination, XRD powder photograph if neccessary.

10. XRD powder photos 1.2 amps - blue crystals Result - Pumpellyite.
11. XRD scan Rejects - Zircon major, Fluorapatite, Sphene.
12. XRF scan —

Weights of samples, size fractions and magnetic fractions.

	Sample No.	Gross weight of sample	Size fraction selected	Total weight of this fraction	Weight of heavy minerals	Weight % heavies	Weight of magnetite	Weight of 0.2 amps	Weight of 0.35 amps	Weight of 0.45 amps	Weight of 0.75 amps	Weight of 1.2 amps	Weight of non-magnetics
raywacke and Argillites	T-13	2.780k	3ϕ	27.0gm	0.209gm	1.74%	0.003gm	0.003gm	0.046gm	0.057gm	0.079gm	0.018gm	0.003gm
	T-12	2.724	3ϕ	100.7	1.896	1.88	0.010	0.037	0.352	0.404	0.753	0.285	0.055
lpine Schists	T-10	5.334	4ϕ	691.6	5.464	0.79	0.062	0.488	1.206	0.743	1.771	0.556	0.638
	T-9 3ϕ	4.710	3ϕ	1455.6	6.452	0.44	0.310	0.469	3.557	0.834	0.815	0.180	0.287
	T-9 4ϕ	4.710	4ϕ	1490.6	4.090	0.27	0.000	0.158	2.375	0.461	0.681	0.125	0.290
	T-3	5.249	4ϕ	186.5	9.889	5.30	0.067	1.609	4.284	0.989	1.805	0.349	0.786
	T-1	4.653	4ϕ	105.0	5.232	4.98	0.144	0.953	1.600	0.883	0.885	0.229	0.538
uhuan Granites	T-11	8.08	4.0ϕ	640.8	174.598	27.25	28.800	15.900	14.863	66.993	29.426	5.715	12.901
	T-7	5.221	3.0ϕ	105.1	23.525	22.38	5.839	7.436	5.600	0.276	1.277	1.550	1.547
	T-6	8.966	4.0ϕ	173.4	100.878	58.18	67.904	5.541	5.081	7.304	3.638	2.035	9.375
	T-5	6.412	4.0ϕ	107.6	27.767	25.81	9.758	0.761	4.445	7.465	2.247	1.547	1.544
	T-4	5.929	4.0ϕ	130.5	21.005	16.10	9.043	4.039	1.387	2.336	1.498	1.284	1.368
	T-2	5.221	3ϕ + 4ϕ	127.2	3.586	2.82	3.415	0.000	0.000	0.056	0.062	0.028	0.025
	H-7	5.306	4.0ϕ	300.0	62.570	20.86	13.667	8.384	12.995	14.011	5.261	2.815	5.438
	H-4	4.767	4.0ϕ	840.4	27.345	3.25	5.056	3.531	10.263	3.891	1.446	1.085	2.073
	H-1	5.760	4.0ϕ	291.3	86.152	27.86	33.097	6.013	15.767	13.563	4.331	3.221	5.160
ther samples													
Beach	H-10	6.753	3ϕ	1734.2	75.500	4.33	0.906	10.375	53.281	3.116	6.256	0.291	0.822
Beach	H-3	7.292	4ϕ	1675.8	71.043	4.24	1.042	11.269	44.561	2.942	4.160	1.490	5.579
River mouth	H-2	6.000	4ϕ	82.5	41.526	50.03	3.140	1.101	34.716	0.398	0.711	0.189	1.271
Dredge	KD(a)	0.347	4ϕ	27.5	27.496	100.00	0.366	6.360	3.926	0.522	1.163	1.116	6.043
Concentrate	KD(b)	0.340	4ϕ	340.0	340.0	100.00	176.1	54.3	17.200	1.200	5.8	4.7	77.7

Table 3:2

Weight Percentage of Magnetic Cuts of Total Heavy Mineral Weight.

	Sample No.	Total Weight	Magnetite	0.2 amps	0.35 amps	0.45 amps	0.75 amps	1.2 amps	Rejects
Graywacke & Argillites	T-13	0.209 gm	1.43%	1.43%	22.0%	27.27%	37.79%	8.61%	1.43%
	T-12	1.896	0.52	1.95	18.56	21.30	39.71	15.03	3.05
Alpine Schists	T-10	5.464	1.13	8.93	22.07	13.59	32.41	10.17	11.67
	T-9 3ϕ	4.090	0.00	3.86	58.06	11.27	16.65	3.05	7.09
	T-9 4ϕ	6.452	4.80	7.26	55.13	12.92	12.63	2.78	4.44
	T-3	9.889	0.67	16.27	43.32	10.00	18.25	3.52	7.94
	T-1	5.232	2.75	18.20	24.79	16.87	16.91	4.37	10.28
Tuhuan Granites	T-11	174.60	16.49	9.10	8.51	38.36	16.85	3.27	7.38
	T-7	23.525	24.82	31.60	23.80	1.17	5.42	6.58	6.57
	T-6	100.878	67.31	5.49	5.03	7.24	3.60	2.01	9.29
	T-5	27.767	35.14	2.74	16.00	26.88	8.09	5.57	5.56
	T-4	21.005	43.28	19.22	6.60	11.12	7.13	6.11	6.51
	T-2	3.568	95.23	0.00	0.00	1.56	1.72	0.78	0.69
	H-7	62.571	21.84	13.39	20.76	22.39	8.40	4.49	8.69
	H-4	27.345	18.40	12.91	37.53	14.22	5.28	3.96	7.58
	H-1	81.152	40.78	9.40	19.42	16.71	5.34	3.96	6.35
Other Samples.									
Beach	H-10	75.047	1.20	13.82	70.99	4.15	8.33	0.38	1.09
Beach	H-3	71.043	1.46	15.86	62.72	4.14	5.85	2.09	7.85
River Mouth	H-2	41.526	7.56	2.65	83.60	0.95	1.71	0.45	3.06
Dredge Concentrate	KD(a)	27.469	30.42	23.13	14.27	1.89	4.22	4.05	21.97
Dredge Concentrate	KD(b)	337.00	52.25	16.11	5.10	0.35	1.72	1.39	23.05

CHAPTER 4

TECHNIQUES OF IDENTIFICATION.

1. X-ray Diffraction (XRD) survey scan of magnetic cuts.

Unless mineral species present could be readily identified optically all magnetic fractions of a heavy mineral suite were subjected to an XRD survey scan. From the print-out (Figs. 4-6), the major components could be readily identified. Where there were many different minerals present the resulting print-out was often complicated, but nonetheless definitive information could be gained from careful examination of the peaks. Generally a mineral could be readily detected only if it made up more than 25% of the magnetic fraction while those in lesser proportion might give two or three correspondingly smaller peaks which in many cases were masked by peaks due to the major components.

Preparation. Approximately 0.25gm of sample was finely crushed in an agate crucible. The powder was then mixed with two or three drops of absolute alcohol and spread uniformly over a small area, (approximately 2cm x 2cm), of a glass microscope slide. After complete evaporation of the alcohol the slide was clamped into position within the sample holder compartment of the XRD spectrometer. Each sample was run at a scanning rate of 1^{o} per minute over the range 10^{o} to 75^{o} which covers the angles of strongest reflections for minerals.

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Discussion. This technique is suitable only for detection of major species in a mixture of mineral grains. As the number of different minerals present increases so too does the degree of peak overlap and masking occur. For minerals present at less than 10% of the mixture a more selective identification technique would have to be employed. Figures 4 - 6 are typical XRD survey scan print-outs which illustrate these points. Figure 5 in particular illustrates some of the problems outlined above when there are many different minerals present.

2. XRD Powder Photography.

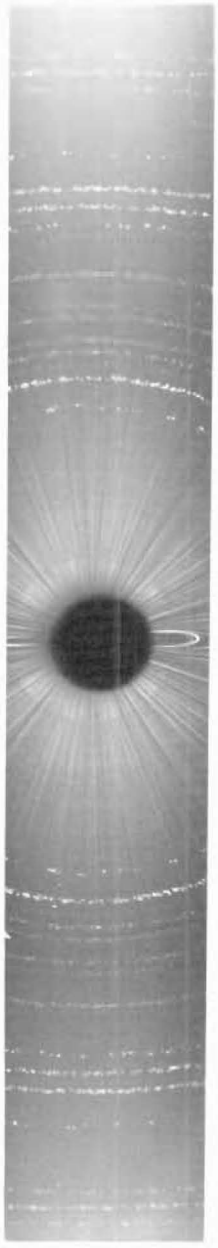
This technique proved invaluable because very small quantities, perhaps six to ten grains from a 4ϕ size fraction, were sufficient to give an adequate X-ray powder photograph. Interpretation of the photograph could be made by one of two possible ways, (a) careful measurement of the lines and comparison of the derived d spacings with those tabulated in the XRD manuals, (b) comparison of the photograph with standard mineral powder photographs.

Preparation. A fine, moist paintbrush was used to lift individual grains from a mixture of minerals and transfer them to another location on a glass microscope slide. This was carried out under a binocular microscope where great care was needed to ensure that the grains were not scattered by an accidental flick of the paintbrush. When a sufficient number of grains had been concentrated a Lindeman tube was rolled across the slide until the wide

FIG. 7

X-RAY DIFFRACTION POWDER PHOTOGRAPH

Mineral Garnet (Spessartine) $Mn_3Al_2Si_3O_{12}$

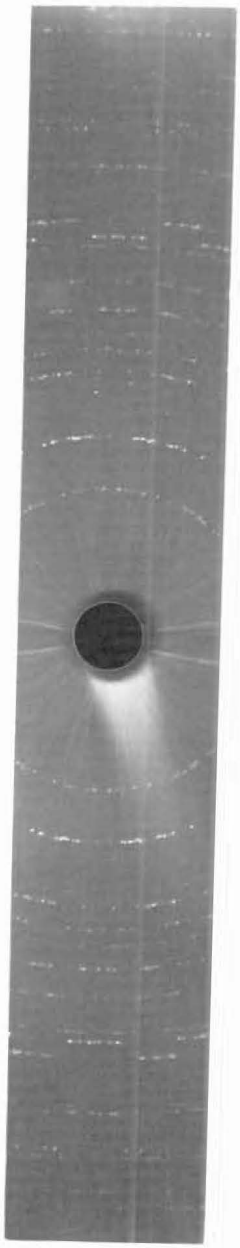


Spacings (mm)	d values	Literature d values	Intensity (%)
	——	4·760	6
	——	3·100	8
60·9	2·935	2·910	25
69·0	2·600	2·600	100
73·0	2·462	2·480	10
76·0	2·368	2·370	16
79·0	2·281	2·280	10
85·0	2·126	2·130	16
88·2	2·051	2·060	6
94·0	1·933	——	—
96·25	1·886	1·886	20
	—	1·836	2
	—	1·797	2
	—	1·710	2
109·0	1·684	1·681	20
	—	1·650	6
114·0	1·615	1·614	30
	——	1·586	6
119·0	1·554	1·557	40
	—	1·482	2
127·9	1·456	1·456	15
145·4	1·312	——	—
149·8	1·268	——	—
154·2	1·237	——	—
164·1	1·179	——	—

FIG. 8

X-RAY DIFFRACTION POWDER PHOTOGRAPH

Mineral Zircon $Zr(SiO_4)$

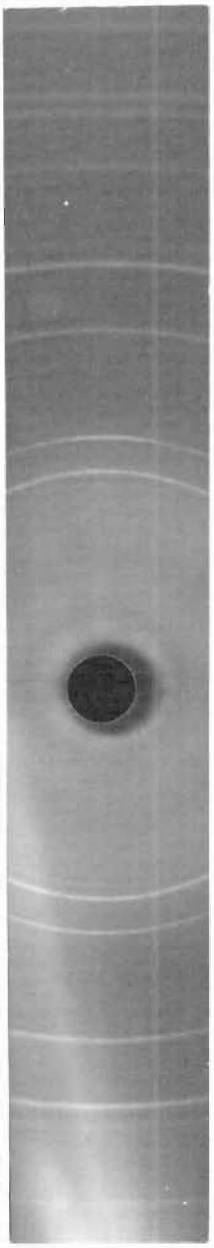


Spacings (mm)	d values	Literature d values	Intensities (%)
39·60	4·480	4·430	45
53·80	3·314	3·330	100
67·00	2·675	2·650	8
70·80	2·535	2·518	45
76·25	2·360	2·336	10
80·75	2·234	2·217	8
87·00	2·080	2·066	20
95·00	1·914	1·908	14
100·40	1·817	1·751	12
106·60	1·719	1·712	40
111·00	1·656	1·651	14
119·00	1·554	1·547	4
125·50	1·481	1·495	4
——	——	1·447	8
135·00	1·388	1·381	10
132·20	1·364	1·362	8
146·20	1·294	1·290	6
152·00	1·252	1·259	8
——	——	1·248	4
161·00	1·193	1·188	12
164·50	1·172	1·167	2

FIG. 9

X-RAY DIFFRACTION POWDER PHOTOGRAPH

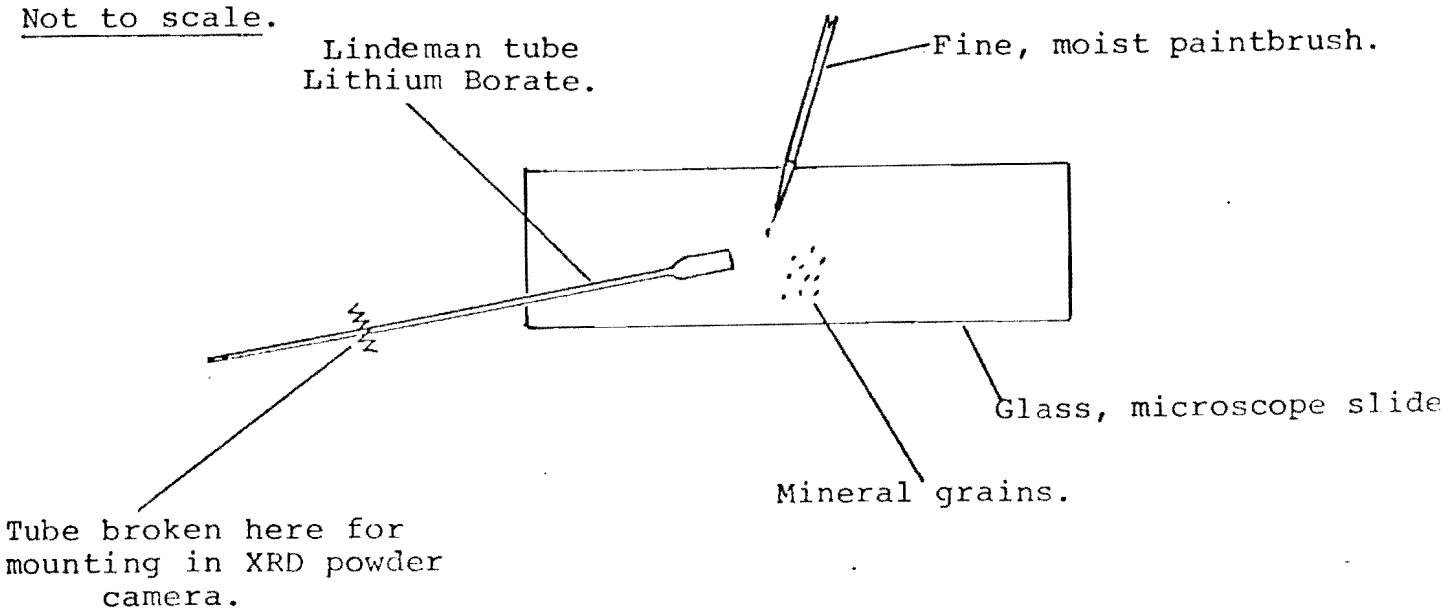
Mineral – Uraninite UO_{2+} (oxygen rich)



Spacings (mm)	d values	Literature d values	Intensity (%)
53·10 (faint)	3·361	——	——
56·25	3·173	3·157	100
66·00	2·714	2·735	48
93·60	1·941	1·934	49
112·40	1·642	1·649	47
116·80 (faint)	1·580	1·579	13
137·50	1·365	1·368	9
151·25	1·257	1·255	18
156·50	1·222	1·223	15

end lay as close as possible to the grains (Fig.10). The grains were transferred individually from the slide into the mouth of the tube. Then holding the tube upright the grains were gently tapped down into the capillary. The tube was carefully broken about 2cm from the sealed end and the portion containing the grains mounted in the powder camera.

Fig. 10 Hand-picking of Grains Under the Binocular Microscope.



Discussion. To ensure sharp, continuous lines on the photograph it would be necessary to crush the sample into a fine powder. However, because of the small quantities used in this identification procedure it was not practicable to do this prior to placing the grains in the Lindeman tube. Figures 7 to 9 show the typical

broken lines which result from an uncrushed sample. These spotty patterns were not disadvantageous to precise measurement of the d values but it made an assessment of relative intensities less reliable, especially with the less intense lines.

3. X-Ray Fluorescence Spectroscopy (XRF).

This technique was used to identify and obtain semi-quantitative information on the radioactive elements present in some samples. In addition, several elemental survey scans were carried out on mineral concentrates (Fig.11).

Preparation. All samples were prepared by the standard method, i.e., at least two grams of sample are mechanically crushed in a ring mill and the resulting powder pressed into a Borax disc.

Discussion. Quantitative analysis by XRF requires careful manipulation of the electronic counting system for optimum stability and consistent performance. Preparation of standards containing known amounts of the element to be determined yields a standard calibration curve which should show a reliable correspondence as between the unknown samples and that curve. Complications such as mass absorption coefficients of individual samples can be accounted for with standard equations. These features are more fully discussed in Chapter 7.

4. Electron Microprobe.

This instrument was used to investigate the elemental composition of individual mineral grains. In particular

Large format diagram too large to be scanned.

Source archive thesis

it was applied to those mineral species which were suspected to be carrying uranium and thorium and as a result the mineral thorite ($ThSiO_4$) was identified. Also, zircon and monazite were shown to be carriers of uranium and thorium (Appendix 2).

Preparation. A dozen mineral grains were sprinkled over a small area of a graphite coated disc. This was then placed in the sample holder of the electron microprobe.

Discussion. Long (1967) has shown that materials to be examined in the electron microprobe must have a well polished surface, free from relief, if accurate quantitative data are to be obtained. As an example he shows the effect of a 0.5 micron deep scratch on the surface of a pyroxene. The additional absorption introduced when the emergent X-rays pass through the material at the edge of the scratch is such that observed concentration of magnesium in a pyroxene of composition En_{50} Fs_{50} is reduced by approximately 10%. This effect was also encountered with our unpolished grain surfaces. The apparent concentration of thorium in one grain of thorite varied from 1% to 50% as the probe was shifted in small increments over the uneven crystal faces. Despite this problem qualitative determination of both major and minor elements in mineral grains was successfully achieved.

5. Optical Identification.

This technique emerged as being of fundamental importance to identification of all minerals. As the writer became

more familiar with the various minerals increasing reliance was placed on optical properties with occasional confirmation from an XRD powder photograph or survey scan.

Preparation. Either several identical grains or a mixture of minerals was placed on a microscope slide for initial examination in reflected light under a binocular microscope. Following this the grains were placed in an oil of known refractive index for more detailed optical examination in transmitted light.

Discussion. In reflected light features such as crystal shape, crystal faces, lustre and colour are obtained without difficulty. Those minerals with a high refractive index, monazite, zircon and cassiterite, sparkle noticeably. Tourmaline consists of distinctive, six-sided crystals while zircon and monazite are often distinctly euhedral. Granite sphene showed diamond-shaped faces and an orange colour while schist sphene consisted of either white or black, semi-opaque bipyramids. Often these "superficial" features alone are sufficient to identify a mineral.

Immersion in an oil beneath a cover slip and examination in polarised light provides much additional information. The refractive index (RI) of the oil was most often 1.65 (α-bromo-napthalene) as it provides an excellent initial reference point. By carefully following the movement of the Becke line at the crystal extremities each mineral can be classified in the following manner: RI = 1.65, $<<1.65$, <1.65, >1.65, $>>1.65$. Where a more

precise determination was required immersion in oils of varying RI's was carried out.

Relief, pleochroism, cleavage, extinction angles and birefringence could also be investigated although darkly coloured or bulky grains were difficult to examine in transmitted light. Many species give an excellent interence figure, mica's having a uniaxial figure while epidote gives a characteristic biaxial negative interference figure with a large axial angle (2V). Closely related minerals such as epidote and clinozoisite are difficult to distinguish by X-ray techniques. For these species additional information obtained from elucidation of their optical properties is required. In fact the lower birefringence and biaxial positive interference figure of clinozoisite conclusively distinguishes it from the optically negative epidote.

CHAPTER 5

MINERALS OBTAINED FROM THE TARAMAKAU CATCHMENT.

For reference purposes the minerals may be conveniently listed in terms of their origin ((a)-(b)) and/or occurrence ((c)-(e)).

(a) Minerals derived from the Alpine schists and graywackes.

Apatite, biotite, chlorite, epidote, garnet (almandine), ilmenite, leucoxene, magnetite, muscovite, pyrite, rutile, scheelite, sphene, tourmaline, tremolite-actinolite, zircon.

(b) Minerals derived from the Tuhuan granites.

Anatase, apatite, biotite, chlorite, clinozoisite, diopside, epidote, garnet (spessartine), hornblende, ilmenite, magnetite, leucoxene, pyrite, sphene, tourmaline, zircon.

(c) Minerals constituting the dredge concentrate.

Apatite, biotite, cassiterite, chlorite, diopside, epidote, garnet (almandine and spessartine), gold, hornblende, ilmenite, leucoxene, magnetite, monazite, muscovite, pyrite, rutile, scheelite, sphene, tourmaline, thorite, uraninite, zircon.

(d) Minerals at the river mouth.

Biotite, diopside, enstatite, epidote, garnet (almandine), hornblende, ilmenite, magnetite, sphene, tremolite, tourmaline, rutile, zircon.

(e) Minerals on the beaches north and south of the river mouth.

Biotite, diopside, enstatite, epidote, garnet, hornblende, ilmenite, magnetite, pumpellyite, rutile, sphene, tremolite-actinolite, zircon.

TABLE 5:1

COMPOSITION OF MAGNETIC FRACTIONS

	Sample No.	Magnetite (hand magnet)	0.2 Amps	0.35 Amps	0.45 Amps	0.75 Amps	1.2 Amps	Rejects (non-magnetics)
Graywacke and Argillites	T-13	MM.	II.	II (altered), GG,BB,CC,MuMu, E.	EE, I (altering),	EE,SS, (altered material).	SS EE, P,L, (altered material).	SS,Z,PP, LuLu.
	T-12	MM.	II(incl),G. MM(incl),	E,G,Mu,I.	EE,B*	EE,Lu.	SS,P*	SS,Z*,P*,F*.
Alpine Schists	T-10	MM.	II,G*	BB,GG,C*, T*,MM(incl),	EE,CC T*.	EE,B,T*, Tr*,Lu*.	SS,E*, MuMu.	SS,Z*,R*, Sc*,F*.
	T-9 3φ	MM.	II,B.	BB,GG,MuMu, C.	E,MuMu, B(altered),T,Tr.	EE,Mu,TT, TrTr,L.	SS,MuMu, R*,P*.	SS,Z,R*,P*, F*.
	T-9 4φ	MM.	II,BB.	BB,MuMu,GG, CC,H.	BB,MuMu, EE,C.	EE,Mu,B, T*,P*.	SS,MuMu, P*,R*.	SS,Z*,P*,R*, F*.
	T-3	MM.	II,B.	BB,GG,MuMu, C.	E,MuMu, B(altered),T,Tr.	EE,Mu,TT, TrTr,L.	SS,MuMu, R*,P*.	SS,Z,R*,P*, F*.
	T-1	MM.	II,B,G*.	GG,B,C,I, MuMu	EE,Mu,CC, L Biotite→Chlorite.	EE,T,MuMu.	SS,P,T*, TrTr,R*.	SS,Z*,Q, R*,Tr*.
Tuhuan Granites	T-11	MM.	B,H,G.	HH,B,E, GG,C.	HH,EE, B,L.	EE,D, H(brown & green).	SS,FF,P*,A*, CC.	ZZ,FF, S,L,P*.
	T-7	MM.	BB,I,L.	HH,B E,LL	HH,L,SS (incl), EE, BB.	EE,L,B,D,A	SS,ZZ,P,A,T.	ZZ,PP,A,S FF.
	T-6	MM.	II,G,BB, E (incl).	HH,GG,E,B.	EE,HH, B*,L*.	EE,P*,D,Z*, T*.	SS,F*,P*,A*, Z*.	ZZ,F,S, A*.
	T-5	MM.	EE (incl), HH.	HH,GG,B, EE,C*.	EE,H,DD.	EE,ss,P*.	SS,FF,P*, Z*.	ZZ,S,F, P*.
	T-4	MM.	MM,II,HH, E(incl).	HH,B,G.	HH,E,L, BB,LL.	EE,S,D, PP,Pu*.	SS,P,FF, Q,Pu*.	ZZ,F,A. SS,PP.
	T-2	MM.	No Sample.	No Sample.	E,H,LL.	EE,LL, P*,D*.	SS,P*.	ZZ,S,F, P.
	H-7	MM.	MM,H,B, II.	HH,BB.	HH,B,DD, EE.	EE,D,SS, L.	SS,A,FF,LL.	ZZ,FF,A, P*,S*.
	H-4	MM.	II,H,B, M,G.	HH,B,C,L.	HH,EE.	EE,L,Cl,H, SS.	SS,Z,F,P. (zircon bipyramids*)	ZZ,(bipyramids)*, F,PP.
	H-1	MM.	II,H,B, G.	HH,B,G.	HH,E,LL.	EE,D,L, SS,Cl.	SS,P,F, Pu*.	ZZ,S,FF, PP.
Other Samples Beach	H-10	MM.	II,G*,B.	GG,I,BB, E*.	EE,H,	EE,Tr*,T, S,EnEn,Pu*.	SS,EnEn, R,Pu*.	SS,ZZ, RR.
Beach	H-3	MM.	II,G.	GG,BB.	EE,HH,DD, BB.	EE,S,EnEn, Tr*,T*,P.	SS,EnEn, R*,Tr*,T*.	ZZ,S,R*.
River Mouth	H-2	MM.	II,G*.	GG,II,B.	HH,E,MuMu, G*,B*,D*.	EE,S,D*,P*, Tr*,B*.	SS,R*,Z, EN*,MuMu.	ZZ,R, S (orange & black).(1)
Dredge concentrate	KD(a)	MM.	II,G.	II,GG,H*, B*.	EE,MoMo, Q,Mu*,C*.	Z,MoMo,SS, T*,D*,CaCa.	MoMo,Z,S, CaCa,PP.	ZZ,PP,Gold*,RR, SS,FF,Ca,L*,Sc*, Th*.
Dredge Concentrate	KD(b)	MM.	II,G,B*.	II,GG,H, B.	EE,MoMo,T*, U*,P(framboidal).	PP(framboidal),ZZ, UU,MoMo,S, Th*,T*,D*,Ca.	PP(f),ZZ,MoMo, U,S,Th*,Ca.	ZZ,PP(f),Gold*,RR, SS,FF,Ca,L*,Sc* Th*.

XX = main constituent, > 40%; X = 15-40%; XX = 5 - 15%; X = 1-5%; X* = < 1%. incl. = inclusions present.

Anatase = A; Apatite (Fluorapatite) = F; Biotite = B; Cl = Clinozoisite; Chlorite = C; Cassiterite = Ca; Diopside = D; Enstatite = En; Epidote = E; Garnet = G; Gold = Gold; Hornblende = H; Ilmenite = I; Leucoxene = L; Magnetite = M; Monazite = Mo; Muscovite = Mu; Pyrite = P; Pumpellyite = Pu; Rutile = R; Sphene = S; Scheelite = Sc; Tremolite-Actinolite = Tr; Tourmaline = T; Thorite = Th; Uraninite = U; Zircon = Z.

(1) See page 61.

Table 5:1(a)

Distribution of the Minerals with respect to their Origin and Accumulation.

	Graywackes & Argillites	Alpine Schists	Tuhuan Granites	Dredge Concentrate	River Mouth	Beaches
Anatase			*			
Apatite (Fluorapatite)		*	*	*		
Biotite	*	*	*	*	*	*
Clinozoisite			*			
Chlorite	*	*	*	*		
Cassiterite				*		
Diopside			*	*	*	*
Enstatite					*	*
Epidote	*	*	*	*	*	*
Garnet	*	*	*	*	*	*
Gold				*		
Hornblende			*	*	*	*
Ilmenite	*	*	*	*	*	*
Leucoxene	*	*	*	*		
Magnetite	*	*	*	*	*	*
Monazite				*		
Muscovite	*	*		*	*	
Pyrite	*	*	*	*		
Pumpellyite *			*			*
Rutile		*		*	*	*
Sphene	*	*	*	*	*	*
Scheelite		*		*		
Tremolite		*			*	*
Tourmaline		*	*	*	*	*
Thorite				*		
Uraninite				*		
Zircon	*	*	*	*	*	*

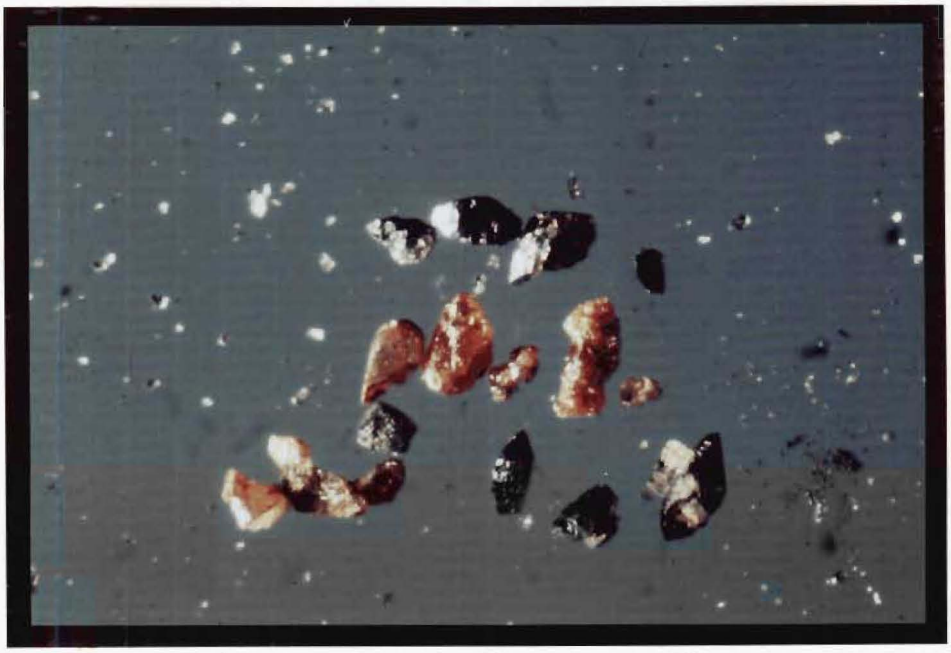
*Pumpellyite was found in only two samples of the Taramakau catchment as a rare constituent.

CHAPTER 6

FORM, CHARACTERISTICS AND ABUNDANCE OF MINERALS.

Plate 3

Anatase TiO_2.

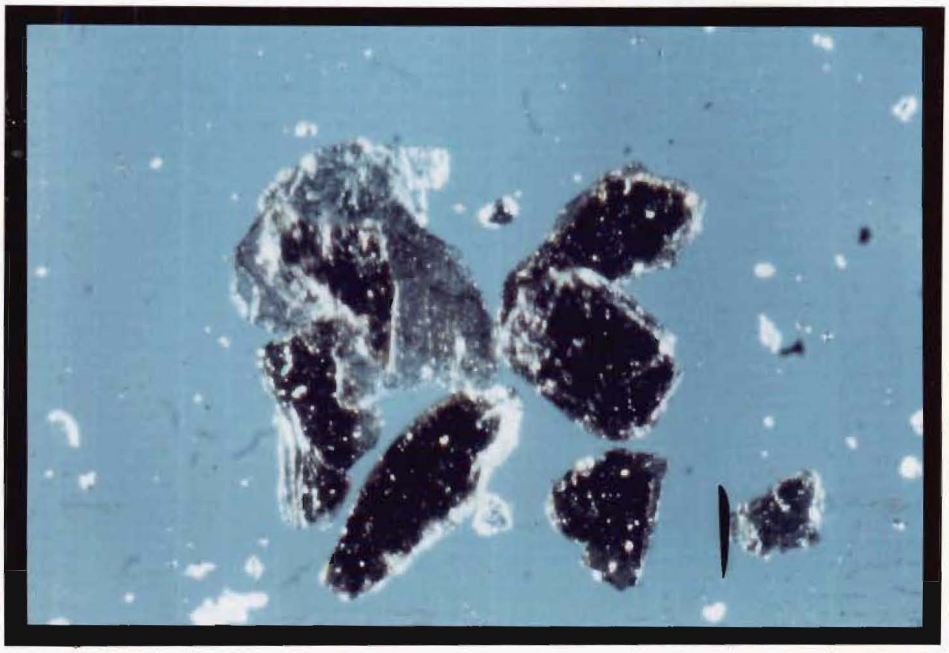


4ϕ (grain size) x64

This occurs as a rare accessory mineral in the Tuhuan granites. It is sometimes found as perfect bipyramids elongated in the direction of the tetragonal axis but more usually as irregular fragments with occasional remnants of the original bipyramidal form. Solution embayments, which in many cases have deeply eroded the original crystals, are a very common feature of this mineral. This 'normal' anatase is non-magnetic and of translucent red colour. However, slightly magnetic, jet black acicular bipyramids were found in the Little Hohonu River.

Plate 4

Biotite $K_2(MgFe^{2+})_{6-4}(Fe^{+3}Al,Ti)_{0-2}[Si_{6-5}Al_{2-3}O_{20}](OH,F)_4$

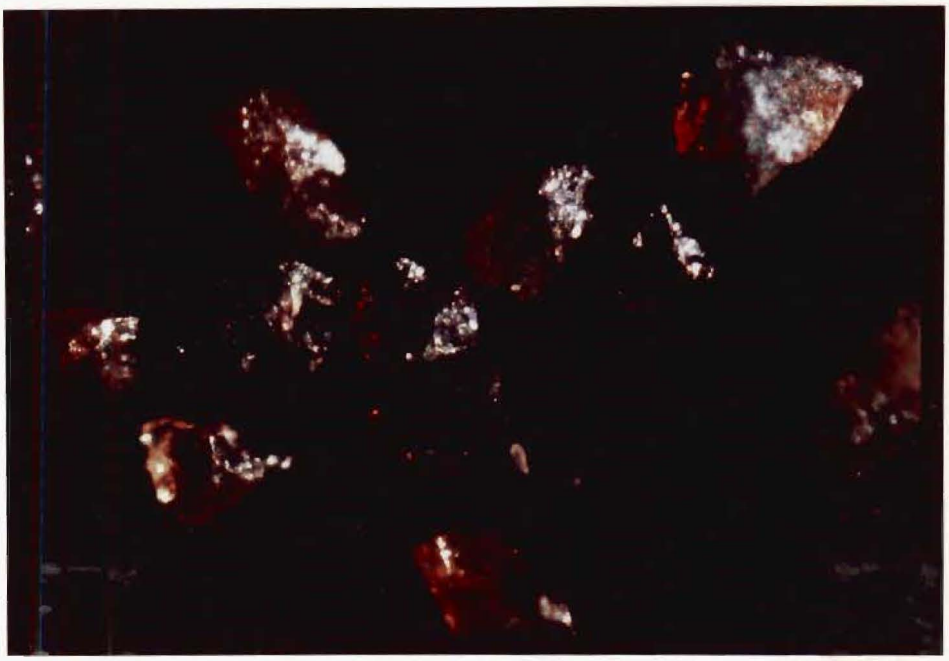


2ϕ x64

As expected, biotite was found in all samples (Table 5:1 & 5:1(a)). It accumulates in the 0.2 and 0.35 amp magnetic fractions.

Plate 5

Cassiterite SnO_2

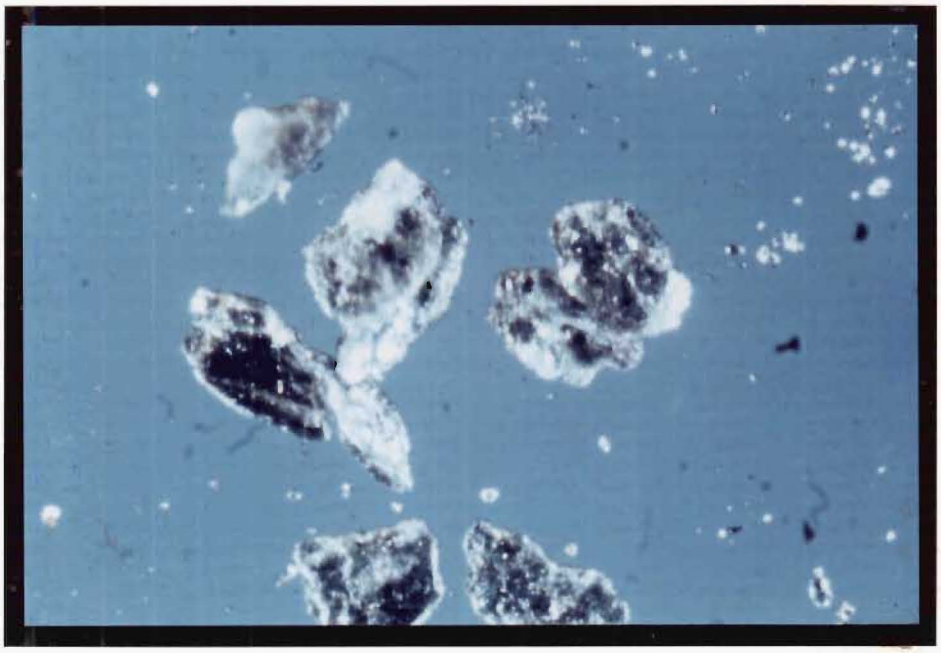


3ϕ x64

This was found only in the heavy mineral suite dredged from the lower morainic gravels immediately overlying the surface of the Miocene mudstone at a depth of some 20 - 25m below the present river-bed. It occurs occasionally as well-formed crystals, but chiefly as red-brown to black angular fragments, especially in the 3ϕ size fraction. Most grains were non-magnetic although a few collected on the 1.2 or 0.75 amp fractions. X-ray diffraction photographs provided reliable identification.

Plate 6

Chlorite $(Mg,Al,Fe)_{12}[(Si,Al)_8O_{20}](OH)_{16}$



2ϕ x64

This is a common constituent of the schist sands, but it also occurs in some granitic samples presumably as an alteration product of biotite. It was particularly common in the kaolinised granites of the Little Hohonu River. Chlorite commonly occurs in the 0.35 amp magnetic fraction.

Plate 7

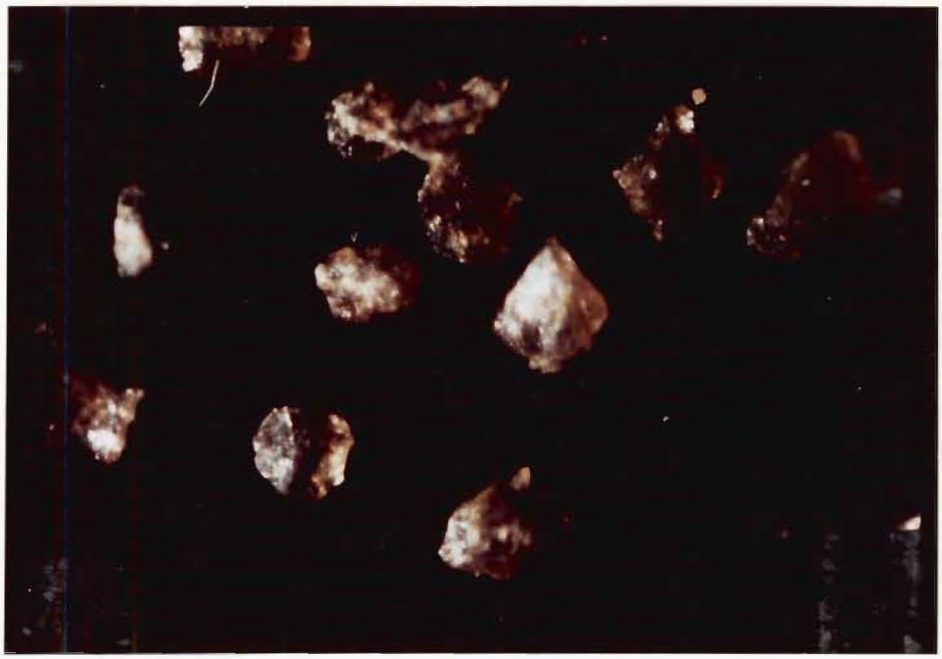
Clinozoisite $Ca_2Al.Al_2O.OH[Si_2O_7][SiO_4]$

4ϕ x64

This was identified as a rare constituent of only one granitic sample, (H-1), although its existance in other such samples cannot be ruled out. It collects in the 0.75 amp fraction along with epidote and sphene. It is of similar orange and yellow colour to the abundant sphene and is difficult to distinguish from epidote under the binocular microscope. Under a polarising microscope the biaxial positive interference figure and birefringence of clinozoisite enable differentiation.

Plate 8

Diopside $Ca[Mg.Mn.Fe][Si_2O_6]$



4ϕ x64

Translucent brown crystals of diopside were present as a minor constituent of 0.75 amp magnetic fractions from granitic samples.

Plate 9

Enstatite $(Mg.Fe^{2+})[SiO_3]$

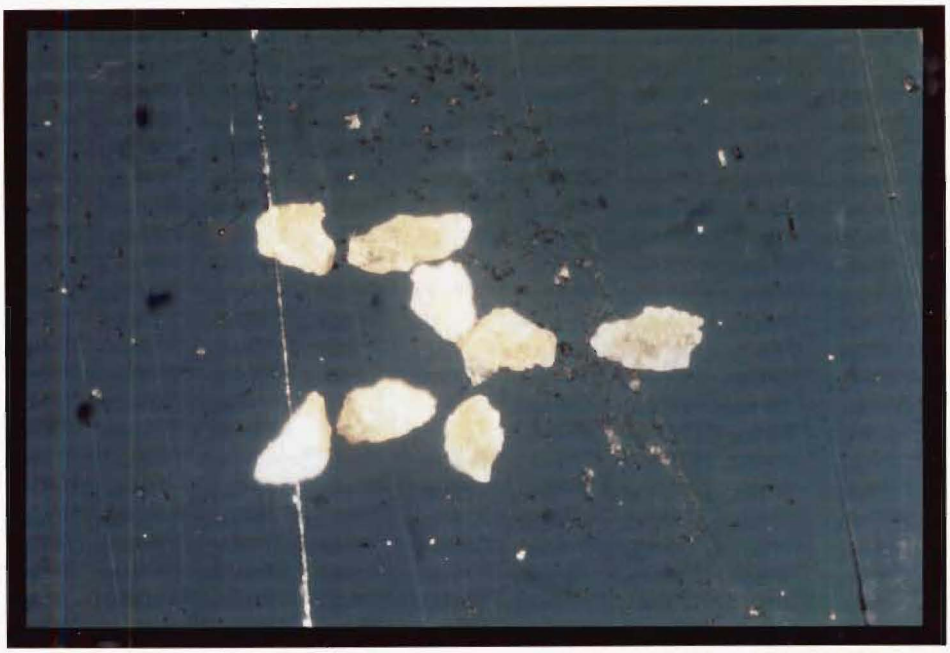
2ϕ x64

Although enstatite was not found in any streams feeding the Taramakau it was common on the beaches both north and south of the river-mouth. These beachsand grains are well-rounded and are of a distinct milky-green colour. The mineral was confined to the 1.2 amp fraction.

Plates 10 and 11

Epidote $CaFe^{3+}Al_2O.OH[Si_2O_7][SiO_4]$

Granitic Epidote 4ϕ x64

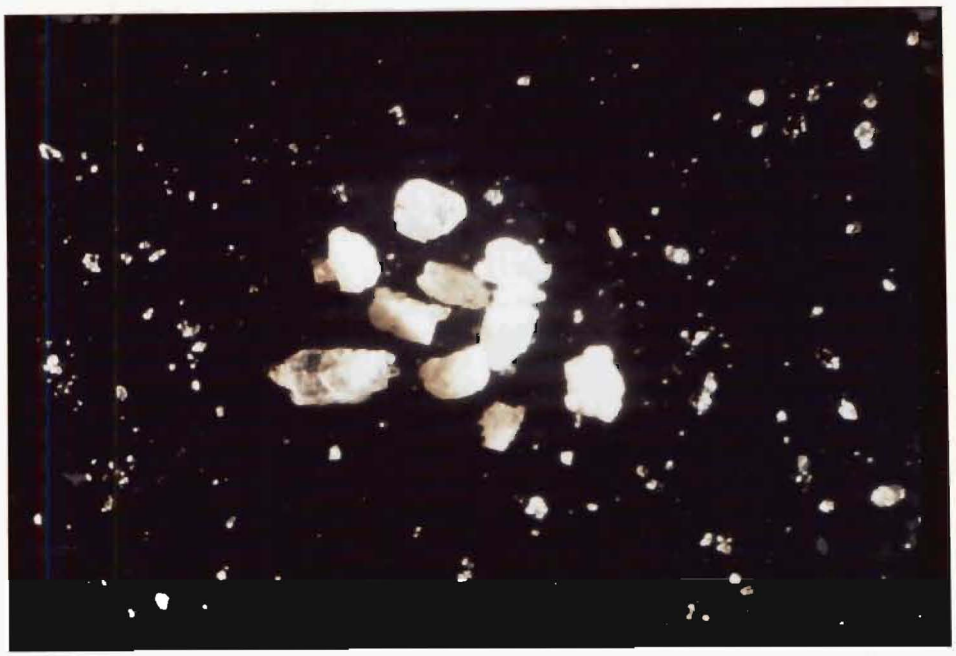


Schist Epidote 3ϕ x64

This is an abundant constituent of most granitic and schist samples. Its colours are quite distinctive - pale green-yellow from granite, but yellow to milky-white from the schists. A distinctive pleochroism shown by granite samples is not displayed so well by the schist mineral. However, both varieties show an excellent $2V > 90^{o}$.

Plate 12

Fluorapotite (Apatite) $Ca_5(PO_4)_3(OH.F.Cl)$



4ϕ x64

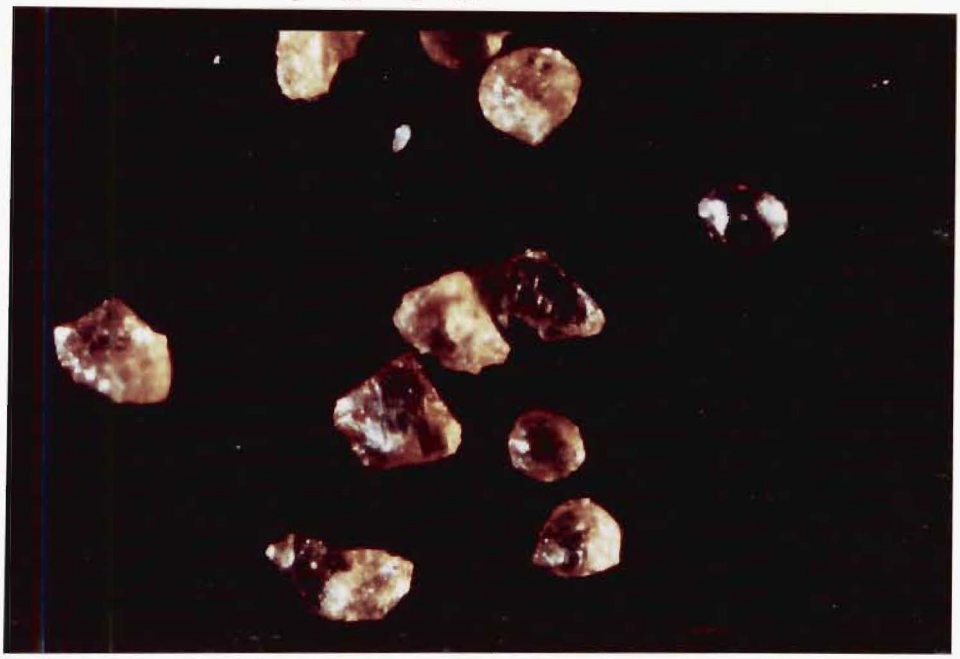
The mineral occurs commonly in granite samples but is a rare detrital product from schists. It accumulates in the nonmagnetic fraction, but because of its low density it is readily separated on the super-panner. The milky-white fragments often showed a residual sub-hexagonal profile of the well-developed crystals. Some unusual black pitted grains of fluorapotite from the graywacke of the Upper Taramakau were identified by X-ray powder photography (see page 111).

Plates 13 and 14

Garnet

Almandine $Fe_3^{+2}Al_2Si_3O_{12}$ 2ϕ x64

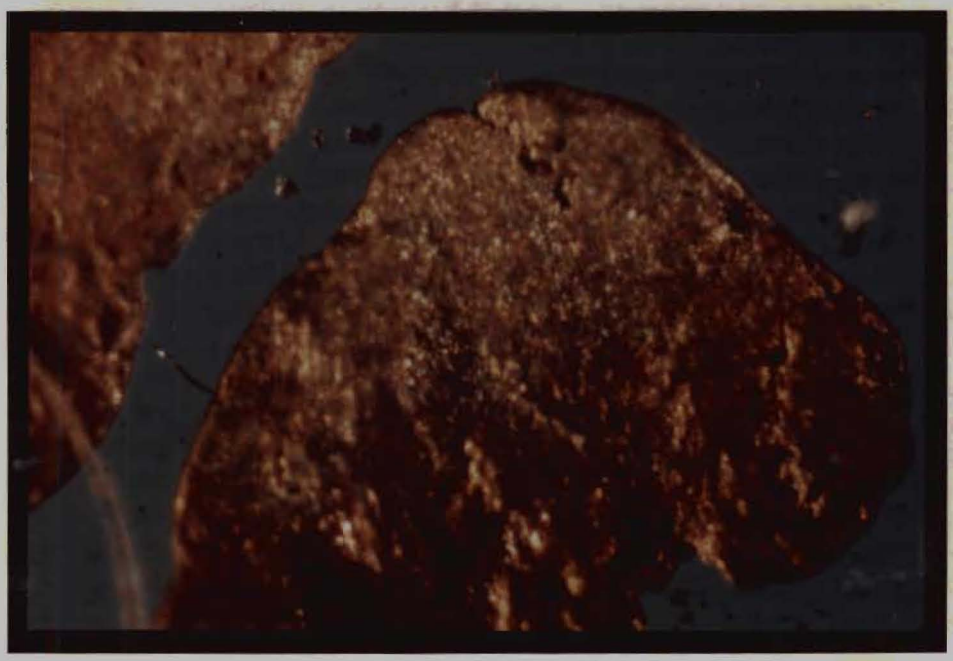
Spessartine $Mn_3Al_2Si_3O_{12}$ 4ϕ x64



Almandine is an abundant constituent of the heavy mineral fractions from schist and beachsand. In granite drainage areas small amounts of spessartine were found only in the vicinity of basaltic dyke swarms, from which it would appear to be derived. This variety was identified on the basis of d values derived from an XRD powder photograph (Fig. 7).

Plate 15

Gold (Au)

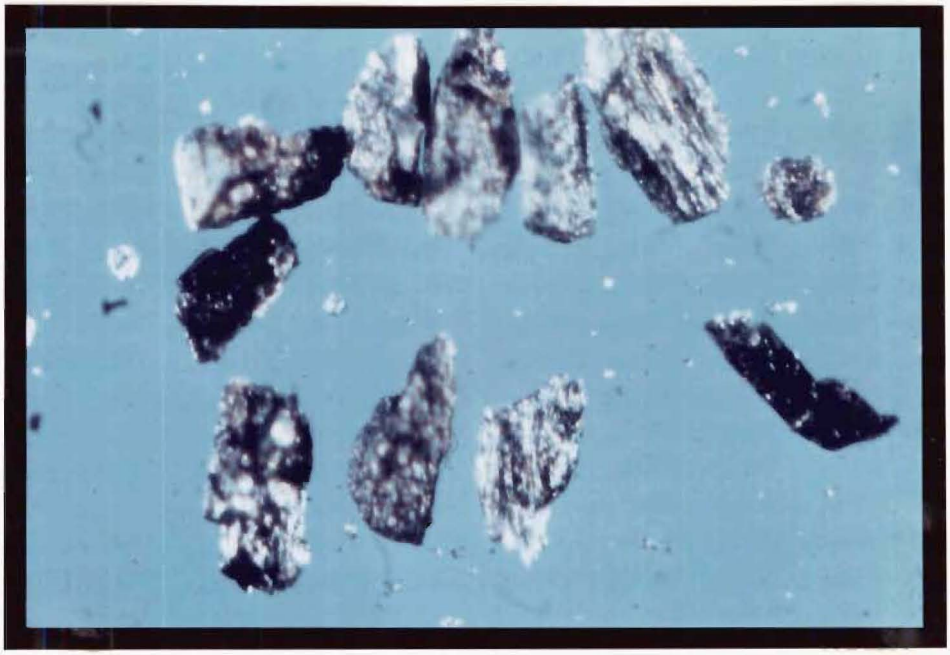


Unsieved x64

Perhaps surprisingly in the light of Westland history and current dredging operations, gold was not found in any of the present stream beds within the Taramakau catchment. The dredged gold is recovered from deeper levels close to the mudstone surface. It is of interest that the [illegible]rinite, cassiterite, thorite and monazite have [illegible] in this same stratum.

Plate 16

Hornblende $(Na,K)_{0-1}Ca_2(Mg,Fe^{+2},Al)_5[Si_{6-7}Al_{2-1}O_{22}](OH,F)_2$

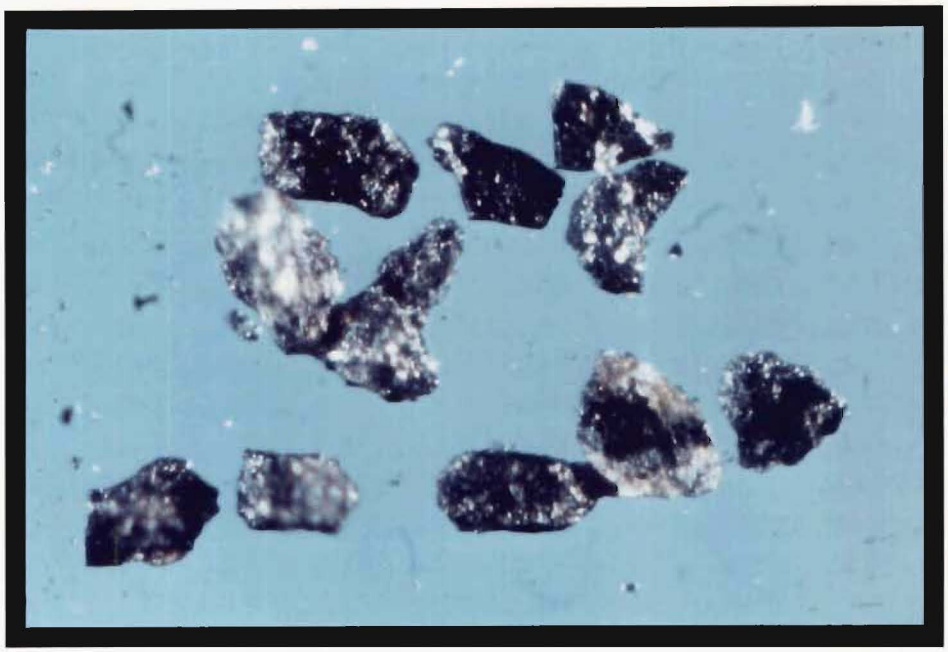


4ϕ x64

The Tuhuan hornblende granites release large quantities of this mineral. The granitic hornblende is dark green, but the thicker grains are almost opaque. A dark-brown variety predominates in the vicinity of dyke swarms, from which it is apparently derived. Hornblende was also identified in the lower Styx River, RS2, (to the south of the Taramakau catchment), where it would appear to be derived from the schists; Mason (1962) reported the occurrence of hornblende from this area. This mineral concentrates in the 0.35 and 0.45 amp fractions.

Plate 17

Ilmenite ($FeTiO_3$)

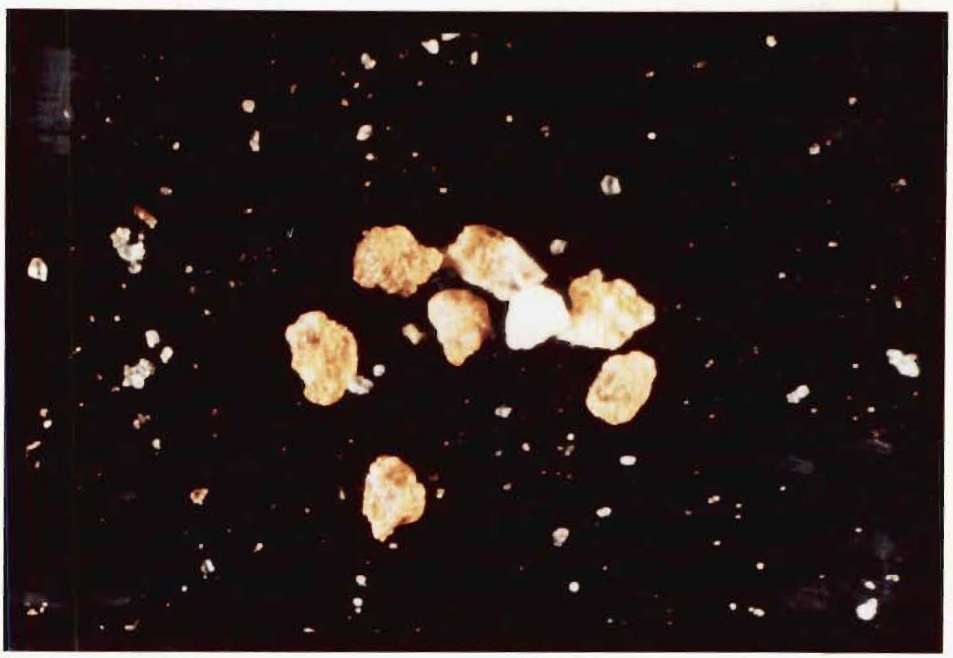


3ϕ x64

Ilmenite accumulating on the beaches is released by both the granites and schists. Apart from its magnetic properties ilmenite can be distinguished by the white flaky patches of quartz which occur on the grain surfaces.

Plate 18

Leucoxene (hydrated, impure TiO_2)

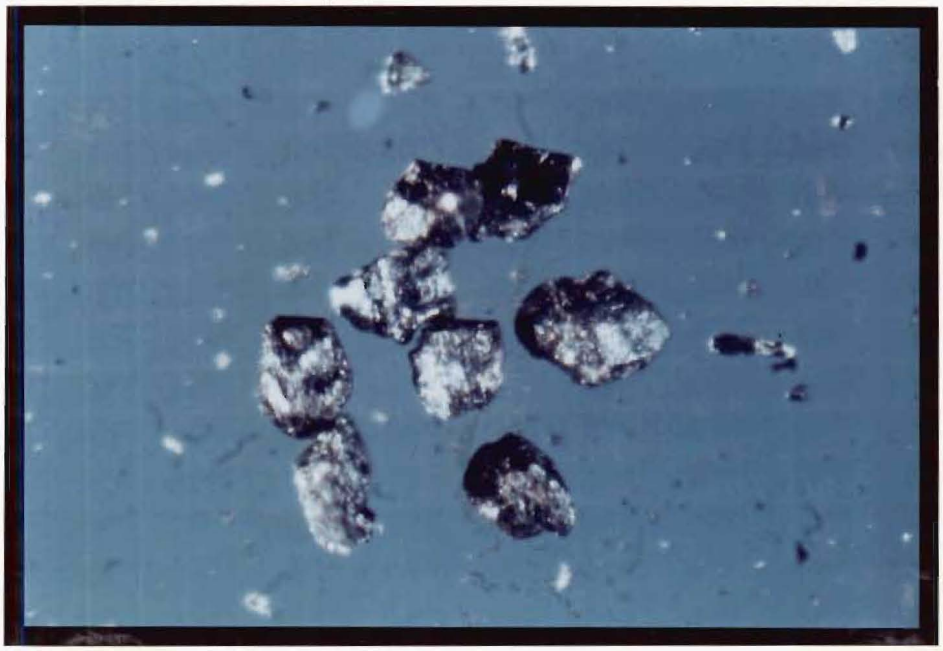


4ϕ x64

Leucoxene, an alteration product of ilmenite or sphene, is common in the granite sands. The granite sphene is much more susceptible to breakdown than sphene from the schists. Leucoxene separated prodominantly in the 0.75 and 1.2 amp fractions, but can be carried into almost any magnetic cut, either as an inclusion within a host mineral, or as partially altered material. The colour ranges from white to dark brown, but is often a darkened yellow.

Plate 19

Magnetite Fe_3O_4

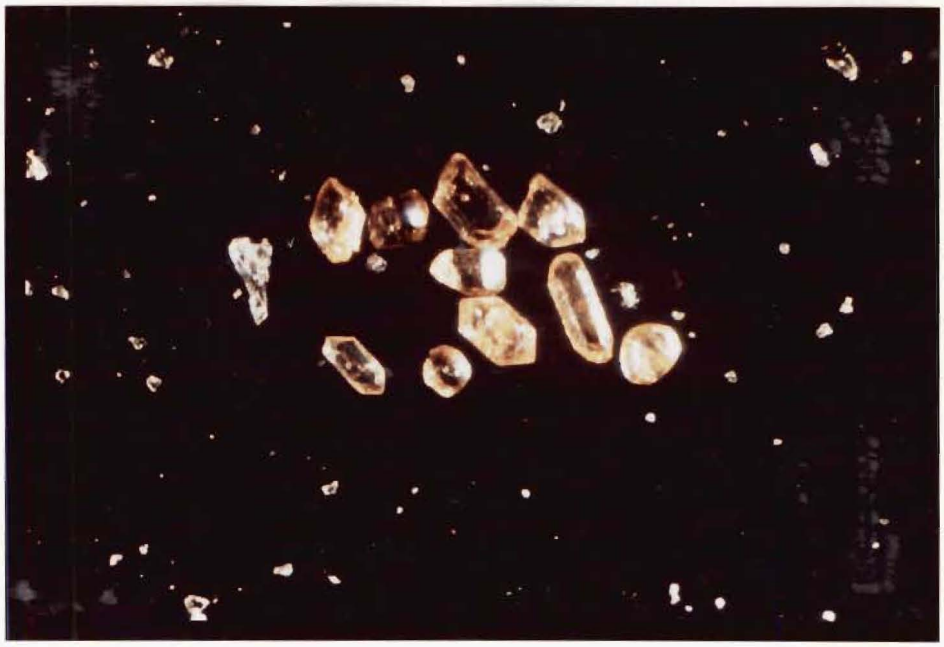


3ϕ x64

This is especially abundant in the granites. In detrital sands from granite the magnetite: ilmenite ratio is 5 : 1, but in the schist sands it is 1 : 9.

Plate 20

Monazite $(Ce,La,Th,Y)PO_4$



4ϕ x64

Like cassiterite, monazite was found in the dredge concentrate where it is represented by two types of grain; larger euhedral crystals and a smaller well-rounded form which clearly has some different history. Monazite shows superficial resemblance to the abundant sphene, but is readily distinguished by its high refractive index and high birefringence. X-ray photography confirmed the identity of the two forms.

Plate 21

Muscovite $K_2Al_4[Si_6Al_2O_{20}](OH,F)_4$

2ϕ x64

As a common constituent of schist mineral suites, muscovite distributes itself over the 0.35, 0.45, 0.75 and 1.2 amp fractions, with the highest concentration at 0.75 amp.

Plate 22

Pumpellyite $Ca_4(MgFe^{+2})(Al,Fe^{3+})_5O(OH)_3[Si_2O_7]_2[SiO_4]_2 2H_2O$

2ϕ x64

This was found as a very rare constituent in two granitic samples (H1 and T4), and in one beach sample (H-10). It has occasionally been reported from granites in other parts of the world, presumably as an alteration product. (Stuwe H., 1958). Grains differed in colour from pale green to distinct blue. Under polarised light individual grains showed a radiating fibrous structure. The d-values from the X-ray powder photographs were identical with reference values over the entire range.

Plates 23 and 24

Pyrite FeS_2

"Normal" Pyrite 4ϕ x64

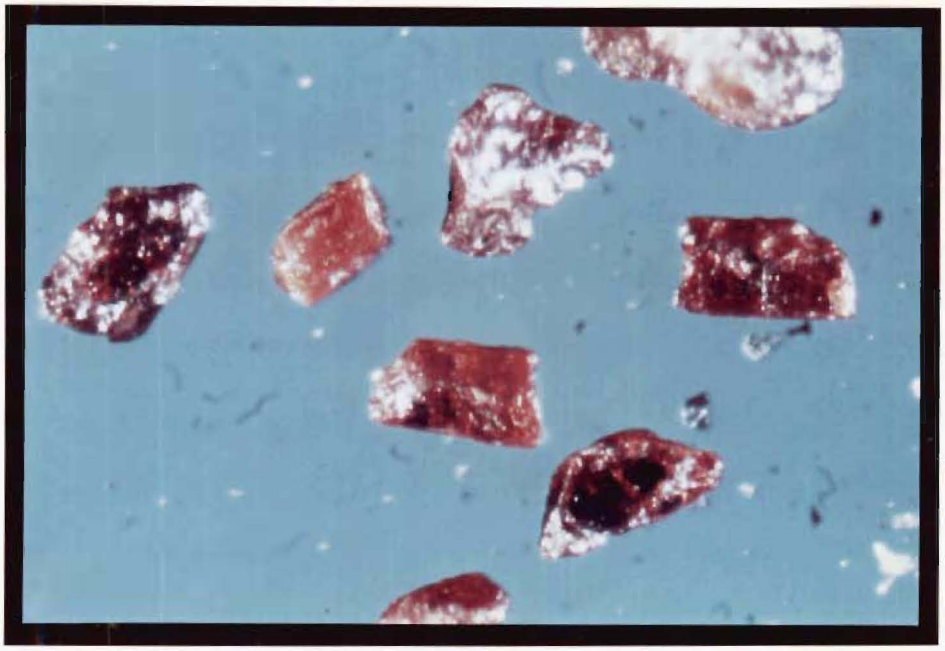
Pseudo-Framboidal Pyrite 4ϕ x64

Most samples contained pyrite as a minor constituent. It ranges from highly reflecting brass-yellow to mottled red-brown. Red-brown cubes from which were amorphous to X-rays were probably limonite pseudomorphs. Samples deeply dredged from levels close to the 'blue-bottom' mudstone interface contained abundant pseudo-framboidal pyrite.

This pyrite, in the form of perfect casts from the in-filling of micro-burrows and upper-miocene micro-fossils has clearly been derived from the mudstone. It differs from the non-magnetic pyrite of the granites and schists in distributing into magnetic fractions as 'high' as 0.75 amp.

Plate 25

Rutile TiO_2

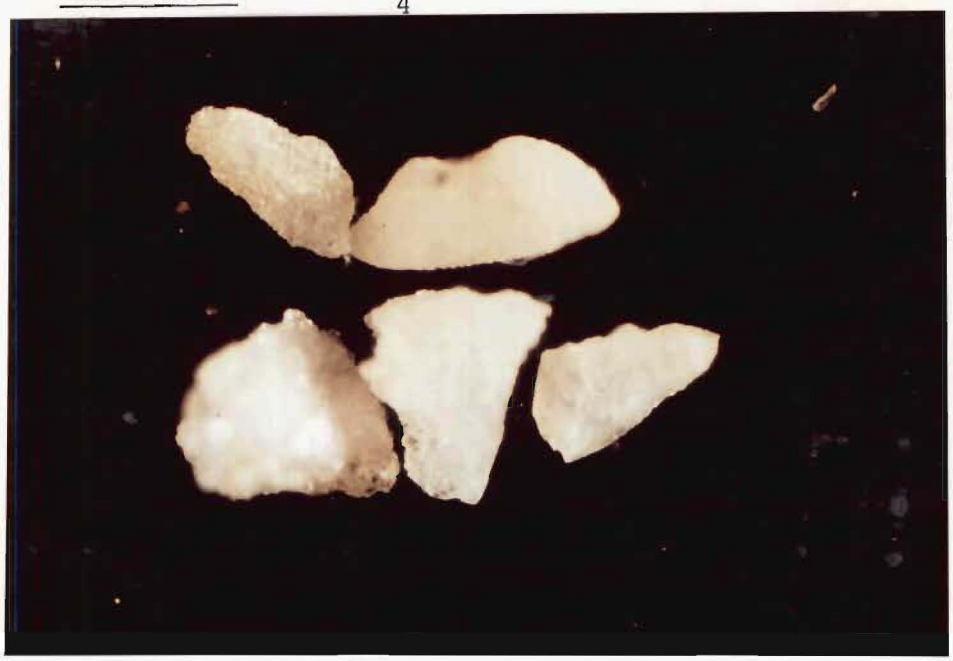


3ϕ x64

As a very rare constituent rutile is present in all schist, river-mouth and beach samples. The elongated red fibrous grains collect only in the non-magnetic fraction.

Plate 26

Scheelite $CaWO_4$



2ϕ x64

Occasional grains of scheelite were identified in samples from Kanieri Dredge concentrate and from the Taipo River. The grains are angular and typically milky-white. Scheelite was also identified in the Kokatahi River (RS5), page 104.

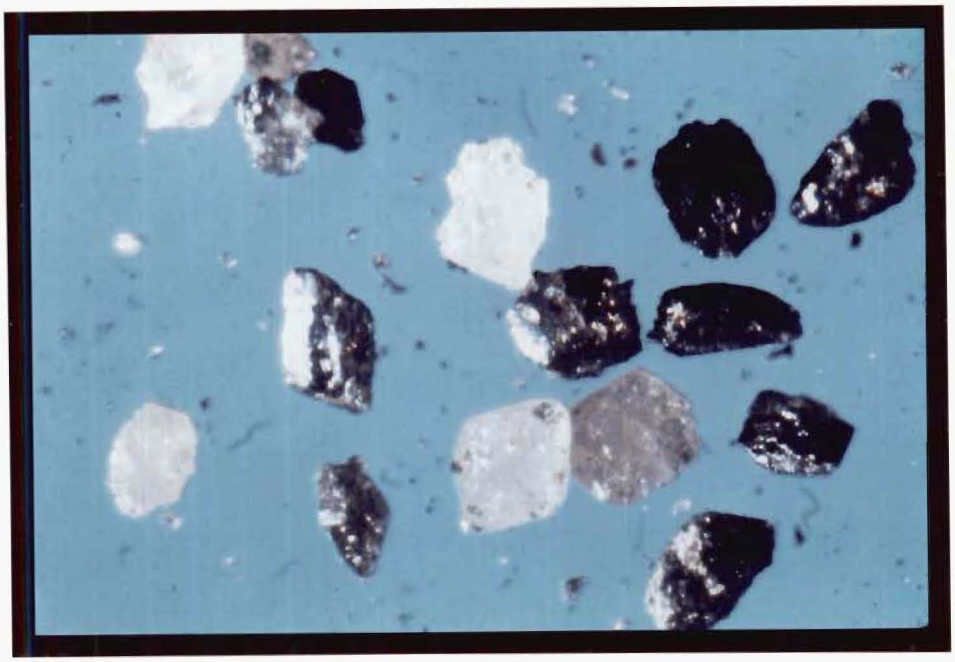
Plates 27 and 28

Sphene $CaO.TiO_2.SiO_2$

Granite Sphene.

4ϕ x64

Schist Sphene.



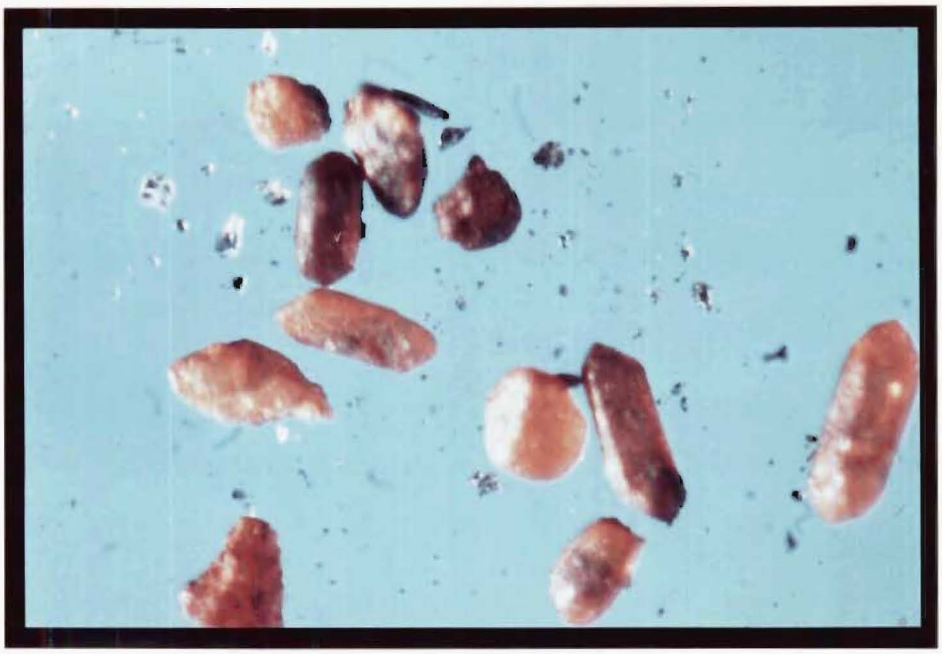
3ϕ x64

This is abundant in all samples, but there is a well-defined difference between sphene from the granites and that from the schists. Granitic sphene consists of pale

orange six-sided euhedral crystals or broken fragments; schist sphene occurs in the form of short tetragonal bipyramids, some of them a semi-opaque white and the remainder black (but with none of intermediate hue). Although the two kinds of sphene give indistinguishable X-ray diffraction photographs there is a considerable difference in their presistence; granitic sphene is seldom found far from its source, but schist sphene is common in the beachsand. However, sphene of granitic origin differs from the non-magnetic schist mineral in containing some magnetic constituent which causes it to collect in the 1.2 amp cut. XRF survey scans showed both varieties to contain calcium, titanium and silicon as major elements. Schist sphene also contained traces of niobium, strontium, lead and rubidium. On the other hand granitic sphene showed a remarkable collection of trace constituents which included niobium, strontium, europium, platinum, lead, iron potassium and tin. Both types showed zirconium, thorium, yttrium and hafnium, all of which could have been due to zircon contamination in the sample.

Plate 29

Thorite ($ThSiO_4$)

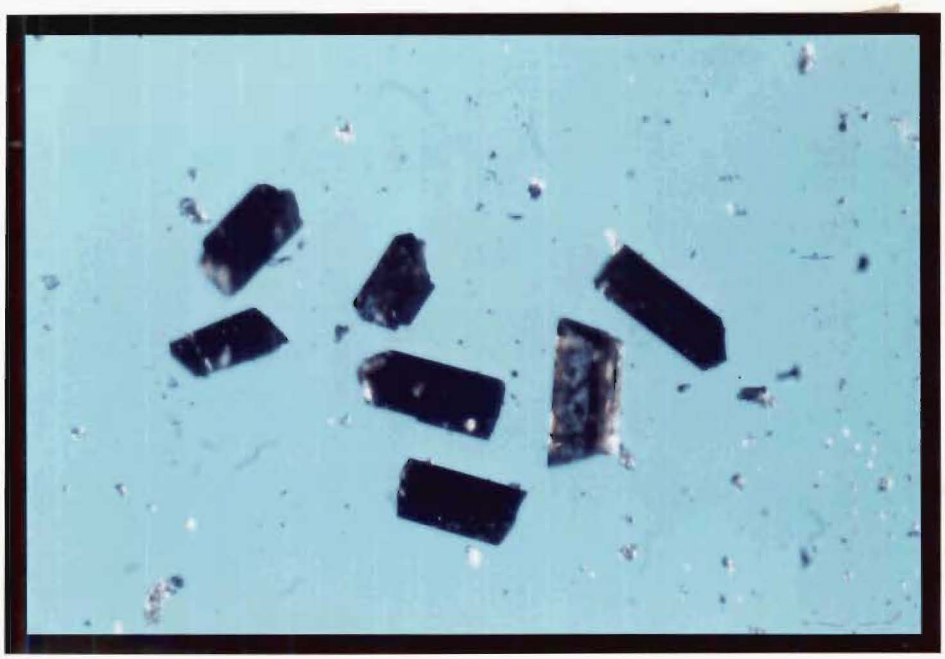


4ϕ x64

A small proportion of the red-brown grains hand-sorted in the first place as cassiterite from dredge concentrate gave high thorium (but no uranium) response under electron micro-probe examination. The appearance of such grains, though closely matching cassiterite, is fully compatible with thorite.

Plate 30

Tourmaline $(Na,Ca)(MgFe^{2+}Al,Li)_3B_3(Al,Fe^{3+})_6O_{27}(OH,F)_4$



4ϕ x64

Although a rare constituent, tourmaline was found in all schist samples. The six-sided columnar crystals of dark grey-brown colour are very distinctive. Not unexpectedly, tourmaline of granitic origin was found in the sediments of the Little Hohonu River, for in this same stream bed a shorl boulder of tourmaline granite containing 5 cm crystals of the massive mineral had already been encountered.

Plate 31

Tremolite-Actinolite $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$

3ϕ x64

This was found in schist sediments, at the river mouth, and on the beaches. The crystals (ranging from clear to light green) are thin and tend to be rectangular, though often with jagged ends. There is evidence of cleavage parallel to the length of the crystal. Tremolite is usually confined to the non-magnetic fraction but sometimes enters the 1.2 amp cut.

Plate 32

Uraninite UO_2 (oxygen rich)

4ϕ x64

The high radioactivity and high uranium values from dredge concentrates were traced to this mineral. The small black, tabular crystals, typically in the 4ϕ sieve fraction, accumulated over the 0.45, 0.75 and 1.2 amp magnetic fractions. The d values of the crystals matched completely those of stoichiometric uraninite, Fig.9).

Plate 33

Zircon $ZrSiO_4$

4ϕ x64

It is particularly abundant in granitic sands in the form of primary euhedral crystals and angular fragments. The crystals are mostly clear but range to dark red-brown and there are occasional hyacinths. A portion of the zircon in samples from French Creek (Hohonu Range) consisted of (small) opaque bipyramids, usually grey but sometimes purple. These metamict crystals showed fission tracks and gave diffuse powder photographs indicative of lattice disorder.

Zircon from the schists was entirely in the form of clear rounded grains.

CHAPTER 7

RADIOACTIVITY.

Most samples show count rates hardly above the background. (Table 7.1). In samples which did give significantly higher counts especially those from granites, no additional minerals were detected and it was assumed that uranium and thorium were carried in zircon, an assumption which was subsequently verified by electron microprobe analysis.

The dredge concentrates however with their very high activities, particularly in the 0.75 and 1.2 amp fractions stand out as quite unusual. Their distinctive heavy minerals as compared with those in the present river-bed are cassiterite, monazite, thorite, uraninite, gold and pseudo-framboidal pyrite, i.e. pyritised internal casts of planktonic foraminifera. Electron microprobe examination and XRF analysis indicated the presence of uranium and/or thorium in zircon, thorite, monazite, and uraninite. Furthermore the heavy minerals vary according to the depth from which they are dredged. In particular pseudo-framboidal pyrite and uraninite occur only in samples from the deepest gravels. The high radioactivity was found in samples taken over a period of eighteen months during which time the dredge moved about 1 km down river.

Table 7:1 Radioactivity Measurements

Units - Counts Time = 1.2 minutes

	Sample No.	Background	Magnetite	0.2 amps	0.35 amps	0.45 amps	0.75 amps	1.2 amps	Non Magnetic
Graywacke & Argillites	T-13	11	11	17	12	10	10	19	11
	T-12	9	18	23	11	16	22	20	13
Alpine Schists	T-10	13	12	14	14	20	11	15	20
	T-9 3ϕ	13	13	13	11	10	17	15	11
	T-9 4ϕ	14	11	14	10	17	14	16	10
	T-3	12	14	7	9	10	9	14	13
	T-1	10	11	18	13	13	12	16	16
Tuhuan granites	T-11	15	9	14	12	14	9	24	26
	T-7	10	15	17	50	45	63	115	123
	T-6	14	21	11	17	46	134	97	136
	T-5	10	14	18	18	27	25	23	39
	T-4	12	17	14	13	37	53	85	391
	T-2	10	4	8	12	10	14	9	12
	H-7	11	9	19	17	17	31	56	45
	H-4	13	17	20	14	44	56	71	130
	H-1	12	18	21	17	21	38	49	77
Other Samples									
Beach	H-10	12	13	11	9	42	24	18	21
Beach	H-3	10	14	17	11	26	16	23	10
River mouth	H-2	11	12	18	27	32	37	69	73
Dredge Concentrate	KD(a)	12	17	14	33	204	537	740	417
Dredge Concentrate	KD(b)	14	13	21	76	625	4026	3435	1102

X-ray Fluorescence Analysis for uranium and thorium.

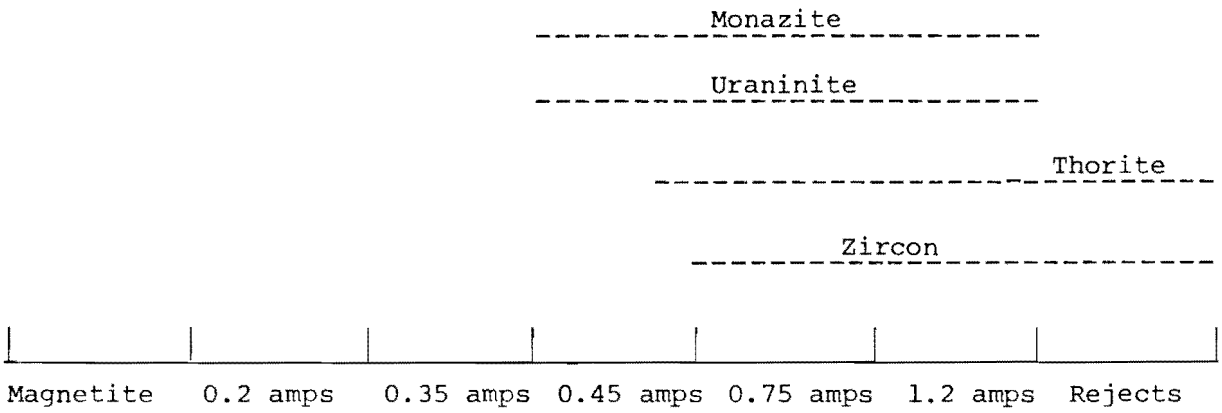
Uranium/thorium calibration curves, (Figs. 13 and 14) were obtained by preparing a series of standard pressed discs, (Tables 7:4 and 7:5). To minimise mass absorption differences between the dredge samples to be analysed and the standard discs, crushed zircon sand was used as the matrix for these standards. This matrix was then spiked with the appropriate concentrations of uranium and thorium. In addition, two samples of dredge concentrate were sent to the Australian Mineral Development Laboratories (Amdel), Adelaide, for independent XRF analysis. Their results were compared with those obtained using the calibration curves established by the writer. There was excellent agreement between thorium results but Amdel reported uranium concentrations approximately 10% higher than those obtained in the first stages of the analytical work. A careful check revealed that the XRF settings used by the writer were not tuned to optimum stability and revised settings effectively shifted the uranium calibration curve upwards by 10%.

Table 7:2 shows that uranium/thorium content varies through both the size fractions and the magnetic fractions. These elements are most abundant in the 4.0ϕ fraction where monazite and uraninite concentrate but they are also found in the 2ϕ, 3ϕ and <4ϕ fractions. The most strongly magnetic fractions contain no radioactive minerals but from 0.45 amps into the less magnetic fractions activity increases considerably. Table 5:1 in Chapter 5 shows that uraninite

first appears at 0.45 amps and to a greater extent at 0.75 amps, while thorite and zircon range from 0.75 amps to the reject fraction. This explains the fluctuating thorium : uranium ratio observed in Table 7:2. Such ratios would depend on the proportions of individual radioactive minerals present in the samples (Fig.12).

Fig.12

Kanieri Dredge Concentrates - Magnetic Distribution of Radioactive Minerals.



With this information it became possible to tabulate the overall activity associated with unrefined dredge concentrate and compare it with the activity of its upgraded equivalent. Upgrading of the concentrate requires, (a) removal of all material coarser than 2.0ϕ, (b) removal of the strongly magnetic minerals, (>0.35 amps), predominately magnetite, ilmenite and garnet.

Table 7:3 illustrates these data along with the fraction of the original concentrate which the upgraded equivalent actually constitutes (column 7). The average concentration of uranium in unrefined dredge concentrate is 0.029% while average thorium content is 0.1%. [The uranium : thorium ratio here is 1:3.5 which compares favourably with a crustal abundance for uranium : thorium of 1:4 (Rankama and Sahama 1949)]. It is worth noting that Nicholson (1955) reported a figure of 0.03% "equivalent U_3O_8" which encompasses the total activity due to thorium and uranium. This figure was obtained from dredge concentrate recovered within the Arahura river catchment. Uranium values obtained by the writer from Taramakau catchment concentrates were in most cases at least twice those reported by Nicholson, presumably a result of conditions which have been favourable for the deposition and accumulation of uraninite. (The occurrence of this mineral in other areas was not reported by Nicholson).

Table 7:2

Radioactivity associated with various size fractions and magnetic fractions of dredge concentrate. *

Date	Sample No.	Size Fraction	Magnetic Fraction	Thorium %	Uranium%
Dec-Jan 1977	(a)	2ϕ	Total sample	0.3	0.15
		3ϕ	Total sample	1.2	0.28
		4ϕ & <4ϕ	Total sample	1.5	0.38
		all <2ϕ	Total sample	1.4	0.32
Nov.1976	(b)	4ϕ	Non-magnetic	3.5	0.43
		4ϕ	0.75 amps	2.1	4.24
Feb.1977	(c)	4ϕ	<0.35 amps	3.65	1.04
March 1977	(d)	<2ϕ	<0.35 amps	3.34	0.77
March 1977	(e)	No analysis of individual fractions. See Table 7:3			

* It must be pointed out that the analytical data in this table should not be taken as representing a systematic survey. When the original analyses were made it had not been anticipated that such high uranium and thorium contents would be found.[2] Nevertheless it is considered that the information presented does provide a reasonable guide as to the overall, recoverable uranium reserves particularly since samples were collected from different dredge locations over a period of eighteen months.

Table 7:3

Radioactivity of unprocessed dredge concentrate compared with upgraded dredge concentrate.

1	2	3	4	5	6	7
Date	Sample	Ungraded Concentrate		Refined Concentrate		Weight % of refined concentrate from unrefined Concentrate.
		u%	Th%	u%	Th%	
Dec-Jan 1976	(a)	0.032	0.102	0.192	0.606	16.85
Nov 1976	(b)	0.044	0.093	0.519	1.095	8.53
Feb 1977	(c)	0.008	0.027	0.272	0.883	3.144
1st March 1977	(d)	0.048	0.224	0.682	3.135	7.159
31st March 1977	(e)	0.013	0.055	0.439	1.825	3.05
Average		0.029	0.100	0.420	1.508	7.746

Table 7:4

Preparation of Thorium Spikes.

Method. Finely crushed zircon sand, (free of uranium and thorium), spiked with 1%, 3% and 5% of thorium as thorium nitrate.

Compound. Thorium nitrate (solution).

Formula. $Th(NO_3)_2.8H_2O$.

Molecular weight of compound. 588.15

Molecular weight of thorium. 232.04.

$\therefore$ 1 gram of compound contains 0.3945 gram of thorium

1% thorium spike.

0.1013 gram $Th(NO_3)_2.8H_2O$ added to 3.8987 gram zircon powder

2% thorium spike.

0.2027 gram of $Th(NO_3)_2.8H_2O$ added to 3.7973 gram zircon powder.

5% thorium spike.

0.5069 gram of $Th(NO_3)_2.8H_2O$ added to 3.4931 gram zircon powder.

Table 7:5

Preparation of Uranium Spikes.

Method. Finely crushed zircon sand, (uranium and thorium free), was spiked with 0.025%, 0.5%, 0.75%, 1.0% uranium as uranyl acetate powder.

Compound. Uranyl acetate.

Formula. $UO_2(CH_3COO)_2.2H_2O$.

Molecular weight of compound 422.13

Molecular weight of uranium 288.03

$\therefore$ 1 gram of compound contains 0.56 gram of uranium.

0.025% uranium spike.

0.0044 gram uranyl acetate added to 9.9956 gram of zircon powder.

0.5% uranium spike.

0.0892 gram uranyl acetate added to 9.9108 gram of zircon powder.

0.75% uranium spike.

0.1339 gram of uranyl acetate added to 9.8667 gram of zircon powder.

1.0% uranium spike.

0.1785 gram uranyl acetate added to 9.8215 of zircon powder.

Fig. 13 Thorium Standard Calibration Curve.

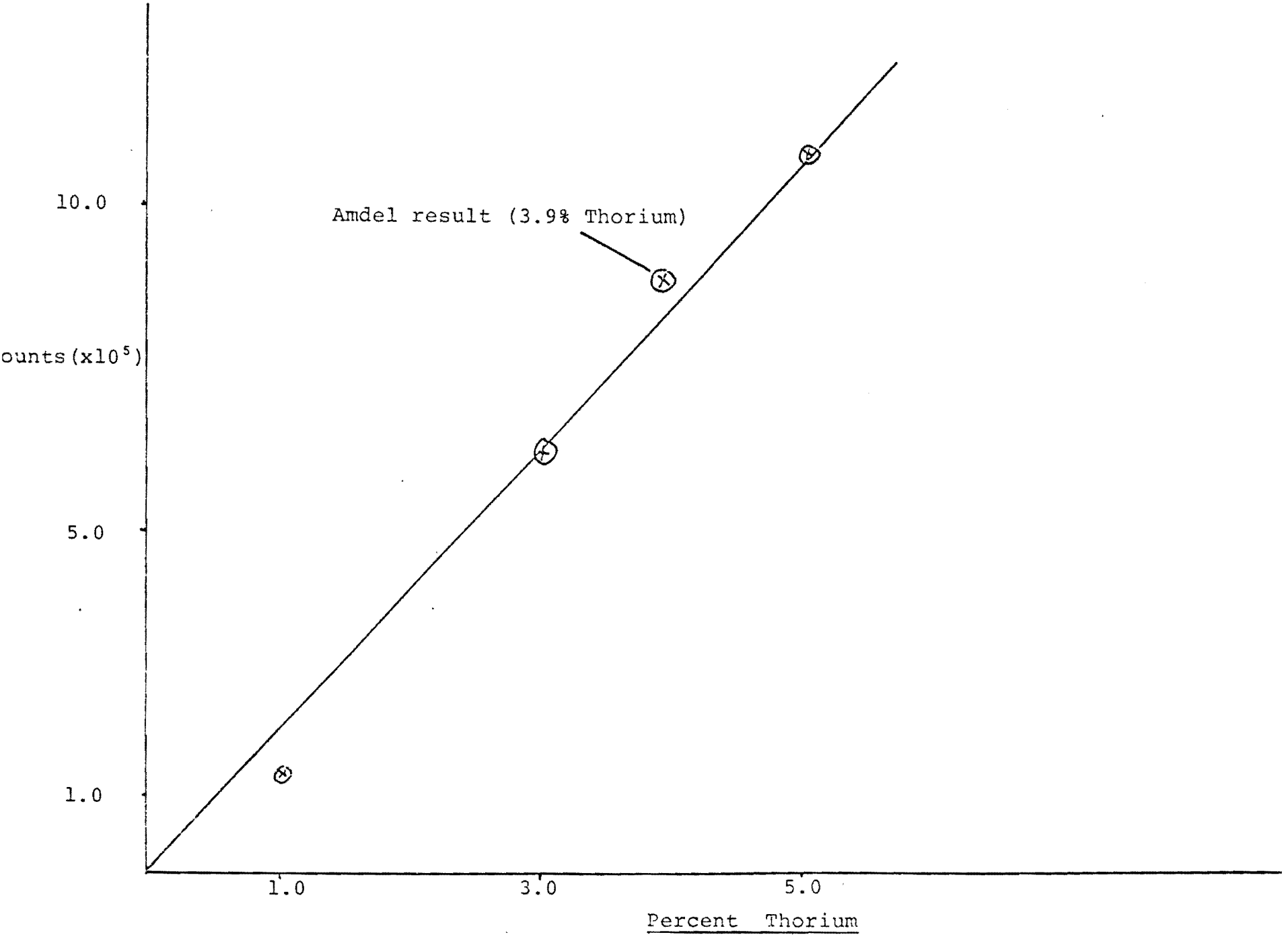
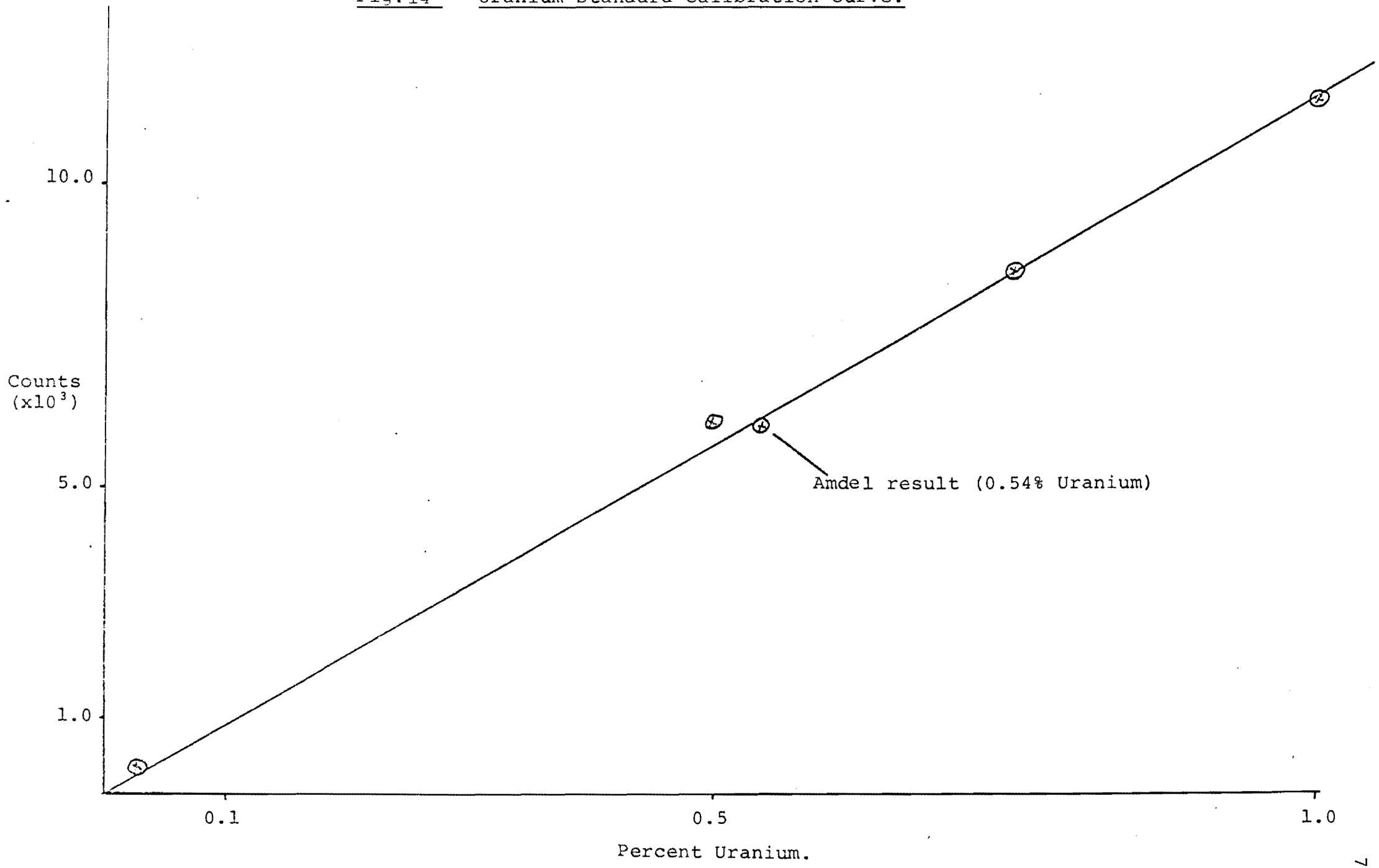


Fig.14 Uranium Standard Calibration Curve.



CHAPTER 8

THE INFLUENCE OF SOURCE ROCKS ON HEAVY MINERAL ASSEMBLAGES.

I. Tuhuan granites vs Alpine Schists as contributors of heavy minerals.

The total area of Tuhuan granite draining into the Taramakau river is small (approximately 44km^2), compared with the extensive drainage pattern extending throughout the Alpine schists and eastwards into the Torlesse graywackes (approximately 480km^2). Furthermore the structure of schist renders it susceptible to rapid weathering with consequent release of heavy minerals whereas the Tuhuan granites are predominantly well indurated, crystalline and resistant to degradation by weathering processes. However, the yield of heavy minerals per equivalent weight of stream sediment derived from granites is about twenty times that from schists, (chapter 3, table 3.1). Thus there are two opposing effects; on the one hand there are large areas of schist and graywackes breaking down completely into fine (silt) material with very efficient release of small quantities of heavy minerals. By comparison there is a limited area of resistant granite breaking down more slowly into sand size material to yield considerably greater quantities of heavy minerals.

Information obtainable from the characteristics of zircon accumulating in the lower reaches of the Taramakau River can be used to place the relative contributions of

the granites and schists on a semi-quantitative basis. Granitic zircon consists of authigenic, euhedral grains with excellent crystal faces and edges, while allogenic zircon from the schists and graywackes is rounded and without well defined faces. The mixing ratio of these two distinct types of zircon can therefore be obtained. In fact grain counts on a sample from the lower Taramakau showed the mixing ratio of schist-type zircon to granitic zircon to be close to 1:1. (Average grain sizes and the consequent weight ratios are slightly higher for the schist mineral). Then magnetite:zircon and ilmenite:zircon ratios can be estimated for each of the two contributing source rocks, (assuming that no selective sedimentation effects could bias these figures). Since the average magnetite:zircon ratio in granite sands ($<2\phi$) is 7:1 and in schist sands 3:1 then up to 70% of the magnetite in the lower Taramakau river is provided by the granites. On the other hand the ilmenite:zircon ratios are: granite sands, 0.5:1 and schist sands, 6:1, which means that more than 90% of the ilmenite carried by the river derives from the schists and graywackes. But further, because metamorphism of the graywackes into schists has produced at least a five-fold increase in the proportion of ilmenite (see page 86), and because field observations suggest denudation of the schist to be faster than that of the graywackes, a high proportion of this ilmenite would be provided exclusively by the schists.

In principle the method can also be applied to obtain information on the relative rates of weathering of the two rock types. However, in practice it is not possible to apply the method with any confidence because both preferential sedimentation effects and field collecting procedures could have lead to considerable concentration of heavy minerals at source sampling sites. Nonetheless the theory may be presented as outlined below and this in turn enables critical discussion of the limitations of the method.

(i) Granites ($44Km^2$)	Rate = r_g	Schists ($220Km^2$) Rate = r_s	Investigative Step.
(ii) Detritus (<1.0ϕ)	a%	Detritus (<1.0ϕ) b%	Field collection; sand size sufficiently small for full release of zircon.
(iii) Fine Sand (<3.0ϕ)	c%	Fine Sand (<3.0ϕ) d%	Zircon concentrated in finer fractions.
(iv) Heavy Minerals	e%	Heavy Minerals f%	Magnetic separation, grain counts.
(v) Zircon		Zircon	Grain counting on composite sample.

The relative rates of zircon release are then equated with the mixing ratio, as below.

It follows that : rate of zircon release from granite,

$$r_{zg} = r_g \times a.c.e.$$

and rate of zircon release from schist,

$$r_{zs} = r_s \times b.d.f.$$

$$\therefore \frac{r_{zg}}{r_{zs}} = \frac{r_g \times a.c.e}{r_s \times b.d.f} = \frac{x}{y}$$

$$\text{or} \qquad \frac{r_g}{r_s} = \frac{x}{y} \times \frac{b.d.f}{a.c.e} \quad ,$$

and therefore the relative rates of zircon release per unit area of granites and schists are given by:

$$\frac{R_g}{R_s} = \frac{x}{y} \times \frac{b.d.f}{a.c.e} \times \frac{220}{44} \quad .$$

Discussion.

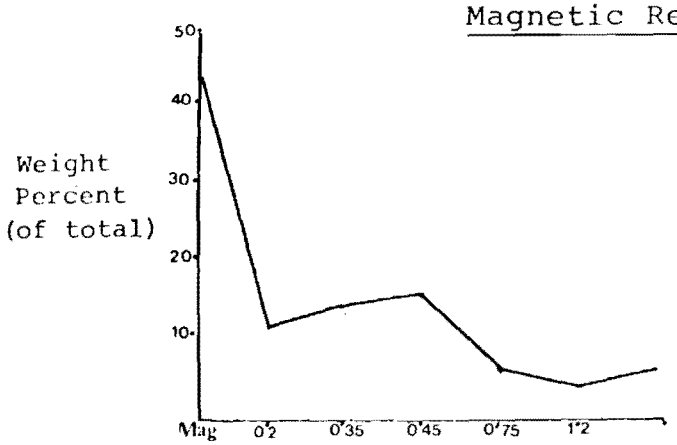
For each of the two rock types there are four component variables in the flow diagram. These are:- (a) denudation of the rocks into detritus [step (i) → (ii)] proceeds at very different rates; (b) the proportion of fine sand in the sediments is significantly different [step (ii) → (iii)]; (c) the yield of heavy minerals [step (iii) → (iv)] depends on the parent rock type; (d) the zircon contents of the heavy mineral suites are quiet distinct [step (iv) → (v)]. These variables are represented by the percentage factors a - f.

Application of this method requires several assumptions. These are, (a) that 1.0ϕ sand is sufficiently fine to provide release of all zircon; (b) that preferential sedimentation does not preferentially concentrate heavy minerals in the streams to any significant degree; (c) that all material released from the parent rocks has been reduced to sand-size detritus at the lower river sites.

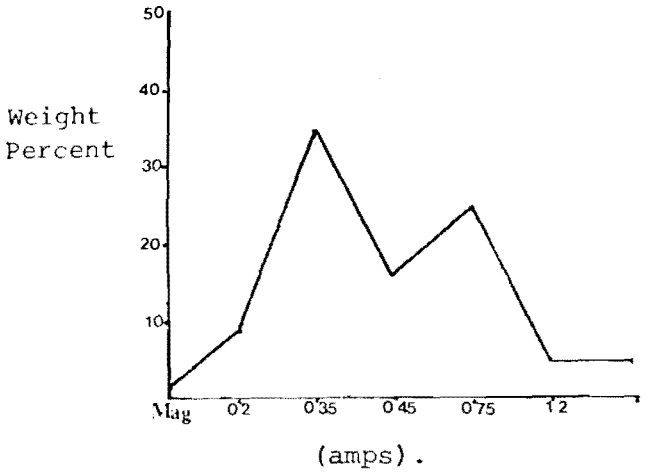
These assumptions would be difficult to test adequately since the techniques employed during this study were not designed for such an exercise. In particular sampling

Fig. 15

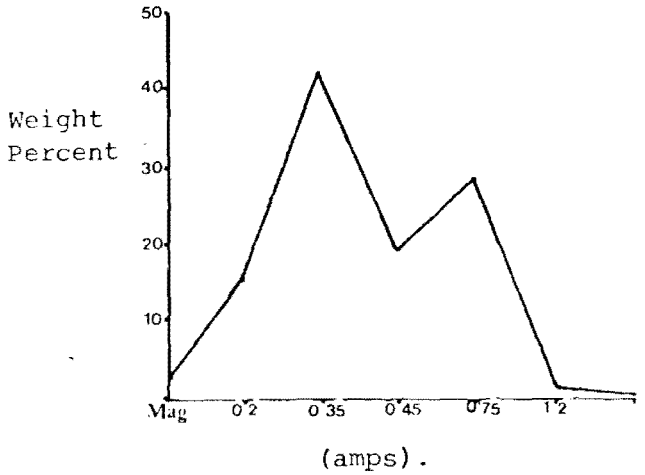
Magnetic Response Profiles (MRP)



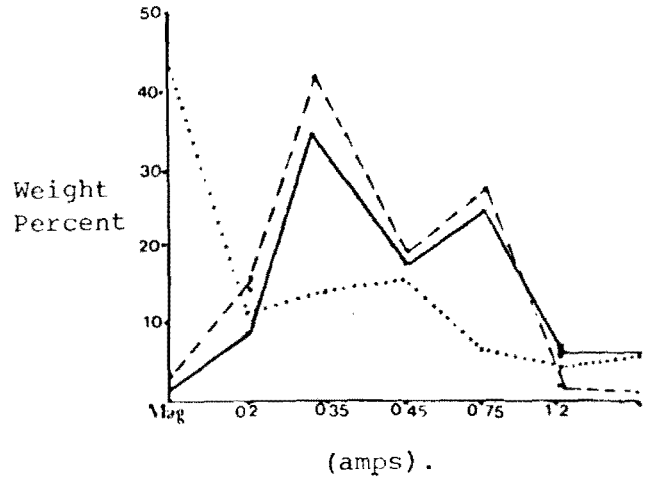
(a) Typical Granite MRP.



(b) Typical Schist MRP.



(c) Lower Taramakau sample MRP



(d) ..... Granite MRP

_____ Schist MRP

------- Lower Taramakau sample MRP

locations were often deliberately chosen where natural concentration of heavy minerals could be expected and often further concentration was effected by panning (see page 16). The results of this study would therefore provide biased sampling parameters. Hence, although theoretically feasible, it is not possible to derive a figure from the available data which would indicate the relative rates of denudation of the schists and granites of the Taramakau catchment.

Magnetic Response Profiles (MRP)

At an early stage of this study it was evident that because of the quite distinctive heavy mineral suites from the granites and the schists, a plot of mineral abundance versus magnetic susceptibility of a sample yields a distinctive profile characteristic of the source rocks from which the sample was derived.

Figs. 15a and 15b show these profiles while Fig. 15c is that of a sample taken from the Lower Taramakau River approximately 1 km from the mouth. The profiles of the schist and lower Taramakau sample are very similar. This similarity clearly illustrated the dominance of schist minerals in the Lower Taramakau River.

Magnetic response profiles should however be used with caution. For example it has been assumed that all species present in the source rocks are still in existence in the Lower Taramakau, i.e., that those minerals which make up the "backbone" of the profiles are persistent enough not to undergo significant destruction as they travel down river.

In fact this is not so; the peak at 0.75 amps in the schist profile (Fig.15b) is due to the abundance of micas in schist samples, but these minerals have a very limited persistence. However, allowing for the theoretical contribution of micas to the Lower Taramakau sample (Fig.15c) the superimposed profiles in Fig. 15d show the observed similarities. It happens that micas were the only non-persistent minerals whose abundance had any significant effect on the shape of the curve.

Various size fractions from both granite and schist samples were monitored to ensure that there was no significant change in the MRP's with grain size. Apart from minor fluctuations the overall profiles remained constant throughout the 2ϕ, 3ϕ and 4ϕ fractions. Consequently comparison of MRP's does not require a uniform size range.

II. Comparison of minerals from Graywackes and Schists.

The assemblages of heavy minerals from these two related rock types are basically similar although as the metamorphic grade increases so too do the abundance and variety of heavy minerals. Mason (1962) has subdivided the graywackes and schists into distinctive zones and has tabulated the distribution of the more abundant minerals in them. Minerals common to both rock types are magnetite, ilmenite, garnet, epidote, biotite, chlorite, muscovite, sphene, pyrite, leucoxene, zircon and apatite. Minerals occurring only in the higher grade schists (Mason's biotite, almandine and oligoclase zones), include tremolite, rutile, scheelite and tourmaline. Mason reported tourmaline from

Torlesse graywackes but it was not recognised in samples collected within the area studied. He also reports clinozoisite as a minor constituent, but since it was not recognised in this study it may have been classed with epidote.

For both the graywackes and the schists the proportion of "heavies" in the 3ϕ and 4ϕ sieve fractions is about 1.5% graywackes. Inferences on metamorphic transformations, involving only heavy detrital accessories, are necessarily limited, but they are compatible with Mason's detailed petrographic and mineralogical study of his graywacke - schist transformation. The typical magnetic distribution (from MRP's) of material from these two sources is:

Magnetic Fraction	Graywackes[a]	Schists[a]	Changes through Metamorphism.
Magnetite	1.0	1.5	No significant change
0.2 amp	1.5	10	Increased ilmenite
0.35 amp	20	40	Increased garnet
0.45 amp	20	12	Increased mica but re-absorption of altered material.
0.75 amp	40	20	
1.2 amp	12	6	
Rejects	2	8	Increased sphene.

(a) Weight percent of total heavy minerals in each magnetic fraction.

The 0.45, 0.75 and 1.2 amp fractions from graywacke contain a predominance of epidote and heavily altered material and some 5% titanium, presumably in the form of leucoxene. Through re-absorption of altered material during

metamorphism these magnetic fractions are smaller in the schist sediments despite the increase in mica and the development of recrystallised epidote. The higher proportions of the 0.2 and 0.35 amp fractions from the schists is due to the growth of ilmenite and of garnet respectively; the larger non-magnetic (reject) fraction is due to increased sphene, as a result of which the proportion of zircon in the non-magnetic fraction is diluted from about 25% to less than 5%. There is no evidence of recrystallisation of zircon. The conversion of pyrite to pyrrhotite remarked upon by Mason is reflected in the low yield of pyrite from schist. Finely divided pyrrhotite is too reactive (non-persistent) to exist in detrital material.

CHAPTER 9

PERSISTENCE AND THE CONSEQUENT BEACHSAND ACCUMULATION OF THE MINERALS.

(1) Persistence.

Although sampling patterns were not designed to make this specifically a persistence study, the systematic approach employed enabled an assessment of the proportions of the constituents of heavy mineral suites recovered at various stages down river. There has emerged a satisfying overall picture of the persistence characteristics of the various species under the particular physical and climatic conditions existing in the Taramakau catchment. This is the more important because persistence is determined not only by hardness, cleavability and resistance to chemical degradation, but also by physical conditions associated with the partiuclar area[4].

As a result of this approach it was possible to place the minerals into the following classes.

Class (a). Minerals found only close to the source rocks: pyrite, anatase, apatite, leucoxene.

Class (b). Minerals with limited persistence; (almost completely eliminated at the river mouth, although they do occur in the main river channels), chlorite, granitic sphene, scheelite, muscovite.

Class (c). Minerals found on the beaches over a restricted area: hornblende, biotite, diopside.

Class (d). Minerals widespread on the beaches: magnetite, epidote, schist sphene, rutile, tremolite, enstatite, ilmenite, tourmaline, garnet, zircon.

TABLE 9:1

Persistence of Minerals[a]

	Tuhuan granites	Alpine Schists	Graywackes	River mouth	Beaches
Class A — Anatase	*				
Apatite (Fluorapatite)	***	*			
Pyrite	*	*	**		
Leucoxene	**	*	***		
Class B — Scheelite		*			
Chlorite	*	**	**		
Muscovite		***	**		
Granitic Sphene	****			*	
Class C — Hornblende	****			**	*
Diopside	**			**	*
Biotite	*	***	**	**	*
Class D — Tremolite		**		*	*
Enstatite					***
Rutile		*		*	**
Schist Sphene		***	**	***	***
Tourmaline	*	**		*	*
Magnetite	****	*	*	**	*
Epidote	***	**	***	***	***
Ilmenite	*	****	**	***	****
Garnet	*	****	**	****	****
Zircon	***	*	*	**	***

increasing persistence ↓

(a)

Those minerals found only in the dredge concentrate, monazite, uraninite, gold, thorite and pseudo-framboidal pyrite are not considered here because corresponding information on their persistence was not obtainable. Nor are the very rare minerals scheelite and pumpellyite considered, although the occurrence of the latter mineral in the Hokitika River and on adjacent beaches (pages 92 & 106) would suggest that it is of the persistent class (d) species.

Table 9:1 presents this information diagramatically, the number of stars indicating the abundance of each mineral in the environment designated by each column heading.

(2) The Beachsand Minerals.

In order to discuss the provenance of the beachsands minerals it is necessary to consider them individually. Those minerals found on the beaches north and/or south of the Taramakau river mouth are, biotite, diopside, epidote, enstatite, hornblende, ilmenite, garnet, magnetite, pumpellyite, sphene, tourmaline, tremolite, rutile, zircon.

Biotite Hardness 2.5 - 3.0.

As biotite is soft and cleaves readily it is almost surprising that it was found on the beaches. The large size of the grains and the rounded rather than flaky form indicates that the beachsand biotite comprises the remnants of fairly large, bulky crystals which have survived with relatively little cleavage and cominution during rather rapid down river transportation. Biotite is an abundant constituent of both the granites and the schists so both rock types are likely sources of the beachsand mineral.

Diopside Hardness 5 - 6.

Diopside was found only in the Tuhuan granites and could not have been derived from any other known source. It is interesting that this mineral was recognised at the river mouth (sample H-2) and on the beach north of the mouth (H-3), but not to the south (H-10). For this reason, and because the predominant longshore drift is northwards

the diopside on the beach must come from the Taramakau granites and not from granite plutons further to the south even though they also contain diopside (page 106). Such a distribution suggests that it does not survive extensive beach transportation.

Enstatite Hardness 5 - 6.

This mineral has not been found within the Taramakau catchment. It could possibly be derived from ultrabasic pods or volcanics within schists to the south of the Taramakau catchment. A little enstatite was found within the river mouth but this was probably caused by tidewater transport.

Epidote Hardness 6 - 7.

Both granites and schists contain epidote. However, because of the dilution effects (page 84) the beachsands contain the schist-derived mineral almost exclusively while only the occasional grains have the typical deep, yellowish-green hue of granitic epidote.

Hornblende Hardness 5 - 6.

This mineral is found only in the Tuhuan granites. Both green and brown hornblende are common on the beaches north and to a lesser extent south of the river mouth. It is a major constituent of some of the mineral suites from granites so that its occurrence on the beaches is understandable.

Garnet Hardness 6.5 - 7.5.

Predictably the schists are almost the exclusive source of beachsand garnet (almandine). It is a major

mineral in all such stream samples and some large crystals, (up to 5cm) occur in massive schist (e.g. in Griffin Stream). Spessartine was found sparsely distributed throughout granitic streams, especially where basaltic dykes are common, but its contribution is negligible.

Magnetite Hardness 5.5 - 6.5.

Magnetite commonly constitutes up to 40% of granitic mineral suites while in schists it seldom exceeds 2%. So in the case of this mineral the contribution from granites to the beachsand mineral is more likely to be significant because approximately 20 times as much magnetite per equivalent weight of sediment is liberated from the granites.

Ilmenite Hardness 5 - 6.

The magnetite - ilmenite ratio in the schist samples is 1:9 while in granites it is 5:1. Undoubtedly almost all of it is derived from the schists.

Pumpellyite Hardness 6.

This mineral was found on the beach south of the Taramakau river mouth. It does not resemble the rather unusual variety found as a very rare constituent of two granite stream sediments. Rather it was typical of the graywacke - schist pumpellyite which was a common constituent in the lower Hokitika River (page 56).

Rutile Hardness 5 - 6.

Since rutile occurs in the schists and was not observed in granites the beachsand mineral would seem to come from schists.

Tourmaline Hardness 7 - 7.5.

Beachsand tourmaline is supplied by both the granites and the schists since it is present as a rare constituent in each.

Tremolite (-Actinolite) Hardness 5 - 5.5.

This mineral has been derived from the schists, in which it is widely distributed.

Sphene Hardness 5 - 5.5.

Beachsand sphene is entirely of the schist type. Orange, granitic sphene does not survive transportation to the beaches although it is still to be found as a rare constituent of the river mouth samples.

Zircon Hardness 7 - 7.5.

Both euhedral and rounded zircons occur in beachsands but the latter generally predominate. With a hardness of 7 - 7.5 and its acknowledged resistance to abrasion it is to be concluded that zircon has been derived from both granites and schists. This is consistent with the ratios found in the lower Taramakau (page 80). Angular fragmented zircons also appear in all beachsands as far south as Jacksons Bay (page 117). Their occurrence in the Taramakau region would seem to be a result of longshore transportation from the south.

CHAPTER 10

KANIERI DREDGE MINERALS

Plate 34

Kanieri Gold Dredge, Lower Taramakau River, February 1976.

The occurrence of the minerals cassiterite, monazite, pseudo-framboidal pyrite, gold, uraninite and thorite which are not carried in the present river-bed poses a special problem especially because all indications are that they occur only at depth (page 49). Investigation of this situation lies well beyond the scope of this study, especially in view of recent intense orogenic activity in this area which could have strongly modified erosional features. Further clarification would perhaps be dependent on the drilling of many test bore-holes with careful analysis of the cores. Nevertheless there are a number of considerations arising from the present field and laboratory studies which suggest possible origins of

these minerals and which are discussed in this chapter. Before proceeding to consider them a brief discussion on features of dredge mineral recovery is in order.

The Kanieri dredge is currently recovering gold in the lower Taramakau River about 5km from the sea-coast. In this area the river channel cuts through moraines and outwash gravels (Suggate 1965), and it is within these gravels that the gold is found. The thickness of the gravels varies but at this location they average 20 metres. They are underlain by a marine mudstone, "blue-bottom", of mid to upper Miocene age. This distinctive blue-coloured mudstone was familiar to the old gold prospectors as the "blue-bottom" defining the lower level of payable gold bearing gravels. The bucket line of the dredge digs 20 metres down to this interface and so recovers not only the heavy minerals carried down the present river, but also any minerals which are buried in the older glacial gravels.

The origin of the pseudo-framboidal pyrite grains is readily explained. They consist of a wide variety of small marine micro-burrow and shell casts. There is often remarkably well defined detail. They have been dated as upper Miocene [5] and must have been derived from the mudstone underlying the gravels, which is of the same age. This is supported by the fact that they appear only in samples obtained when the bucket line was working at the gravel-mudstone interface. The source of the gold has usually been assumed to be the alpine schists and to a lesser extent the Greenland group sediments, although it must be

said that the provenance of West Coast gold in general remains the subject of considerable speculation (McPherson 1971).

The source of the other typically granitic minerals, cassiterite, monazite, thorite and uraninite is not immediately apparent, but the various possibilities can be considered. Briefly these are:

(a) the source rocks of these minerals are no longer exposed.

(b) the source rocks are still exposed within the Taramakau catchment but are not presently contributing detritus.

(c) the minerals are derived from ancient "black-sand leads" buried beneath the present river channel.

(d) the minerals have been transported from the Grey Valley which lies to the north.

(e) in the case of uraninite it may have been formed through deposition in situ from meteoric waters.

(a) The source rocks of the minerals are no longer exposed. Monazite, cassiterite, thorite are typical of granitic origin yet none of these were found in any samples draining the Taramakau granites. However, evidence gained in the present field studies indicates that the Hohonu Range has had a somewhat different history to other grantic plutons within the central Westland region. In chapter 2 observed physical differences within the Hohonu range were discussed although it was found that elemental composition had remained constant (page 11). Thus signs of processes

to be associated with mineralisation were observed; tourmaline-rich granite and Kaolinisation within the Little Hohunu River both suggest the possibility of mineral enrichment although none was found. However the present batholith is the eroded "remnant" of an originally larger structure which has been subject to recent ice scouring. The original "cap rock" may have contained these granitic minerals and although the present "remnant" does not appear to carry them, evidence of mineralisation commonly associated with the formation of cassiterite, monazite, thorite and uraninite still exists. This could explain why such minerals occur only in the deeper, older gravels. Fig.16 illustrates this hypothetical situation; the original source rocks which have been eroded by weathering processes are no longer exposed. It is a possibility that detritus from them could lie buried in the older sediments in the Greenstone Valley and in the outwash fans from the western side of the Hohonu Range (Fig. 1).

(b) The source rocks are still exposed within the Taramakau Valley but are not presently contributing detritus. Suggate (1965) has shown that the main Pleistocene ice flows split into three distinct "tongues" behind and to the east of the Hohonu Range. One of these flowed on each side of the range while in addition a cap of ice formed a westward flowing glacier on the range itself. Erosion of the rocks would have been considerable and at the same time releasing large quantities of minerals. The post-glacial period

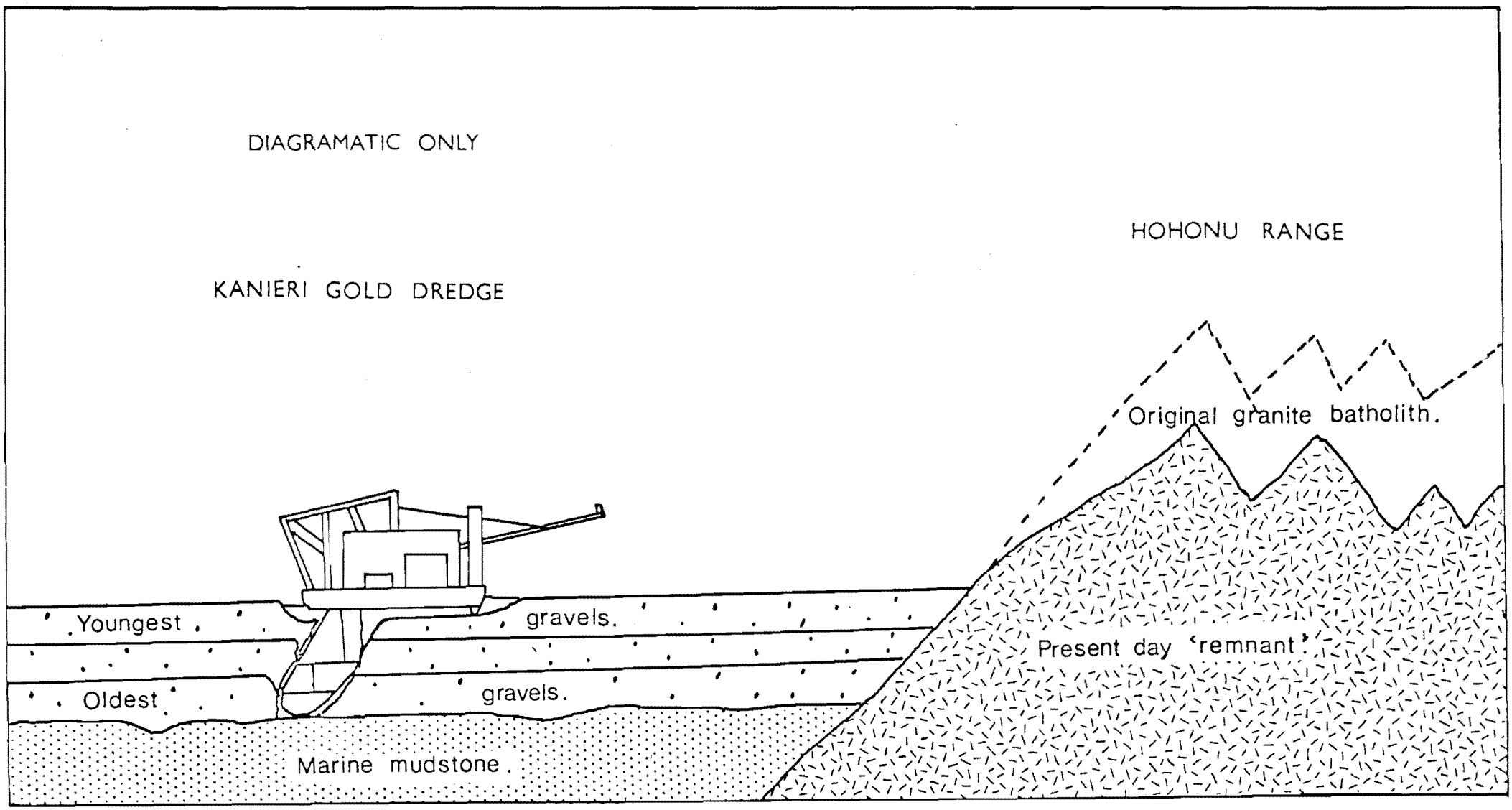


FIG 16. HYPOTHETICAL ORIGIN OF "ANOMALOUS" DREDGE MINERALS.

would have been accompanied by a decreased rate of erosion and the appearance of large cirque areas relatively free from effective erosion at the present time. These rocks may be the source of the "anomalous" granitic minerals which because of the dramatic change in erosional capabilities in the post-glacial periods, are no longer being contributed to the streams of the Hohonu Range.

(c) The minerals are derived from ancient black-sand leads buried beneath the present river channel. Local prospectors have reported several "black-sand leads" in the Lower Taramakau River. These strike at right angles to the river and roughly parallel to the present beaches. It is likely that they are either buried beach leads or river channels and they could contain minerals which have been carried from a distance source[6]. However, none of the "anomolous" minerals show evidence of extensive transportation although many grains of monazite are sufficiently rounded to suggest beach sand transportation. The two types of monazite have two different histories or represent two quite distinct generations, otherwise the mineral grains would all be very angular.

(d) The minerals have been derived from the Grey Valley which lies to the north. Hutton (1950) reported both monazite and tantalum-containing cassiterite in the Grey River Valley to the north of the Taramakau catchment. The rounded dredge monazite is remarkably similar in

colour to the Grey River monazite. XRF analysis on dredge cassiterite showed that it too contains appreciable quantities of tantalum. It is not unreasonable to suggest that the Grey River once flowed as far south as the Taramakau catchment, especially in view of the present course of this river through the Cobden gap and the general geography of the Grey-Taramakau coastal region.

(e) In the case of uraninite it may have been formed through in-situ deposition from meteoric waters.

The occurrence of uraninite is interesting both from an economic and academic viewpoint. Again this mineral is characteristically derived from high temperature granitic environments. De Kun (1965) states that the largest deposits of detrital uraninite in the Witwatersrand system of Africa are associated with gold, pyrite, cassiterite and monazite. The average grain size of the uraninite is 75-100 microns whereas the average diameter of the Taramakau uraninite is 62.5-125 microns (4ϕ)(page 66), and it is associated with gold and pseudo-framboidal pyrite. Further similarities between these two occurrences will be apparent from the following extract from de Kun.

"In the Dominion reef system two reefs contain uranium accompanied by gold. The thick lower reef which contains disseminated uraninite fills low points in the granitic relief. On the other hand the upper reef consisting of fine pebble and grit covers most of the area with a 1" - 4' thick blanket. Since uranium values are an inverse function of

its thickness, 1" thick strips contain 1% U_3O_8. These strips contain 2.5% pyrite, some cassiterite and monazite...."

Features of the Taramakau situation are strikingly similar. Apart from thorite which is only a rare constituent, the "anomalous" minerals monazite, cassiterite and uraninite constitute essentially the same assemblage as De Kun has described. Whether the Taramakau uraninite also occurs in thin blankets or in veinlets remains uncertain. Again it must be emphasised that careful analysis of many bore-hole samples would be necessary to test this theory adequately.

Langford (1977) has shown that with a few exceptions minerals in uranium deposits with a direct igneous (granitic) ancestry, as has been suggested here, are characterised by containing "considerable thorium". On the other hand a large variety of uranium deposits, including some uraninites, are virtually thorium free. Langford remarks:

"For these thorium free deposits there seems to be no consensus whether the ore forming processes are hypogene, with the solutions originating from hydrothermal sources, or supergene, with the ore being deposited by moving ground water. Nearly all who ascribe to the supergene concept visualize the process as happening at considerable depth and the uranium as being introduced by groundwater that has travelled a considerable distance from its source. The surficial concept as used here proposes that the deposits of uraninite originated from uranium that was carried in meteoric waters and deposited by near surface supergene

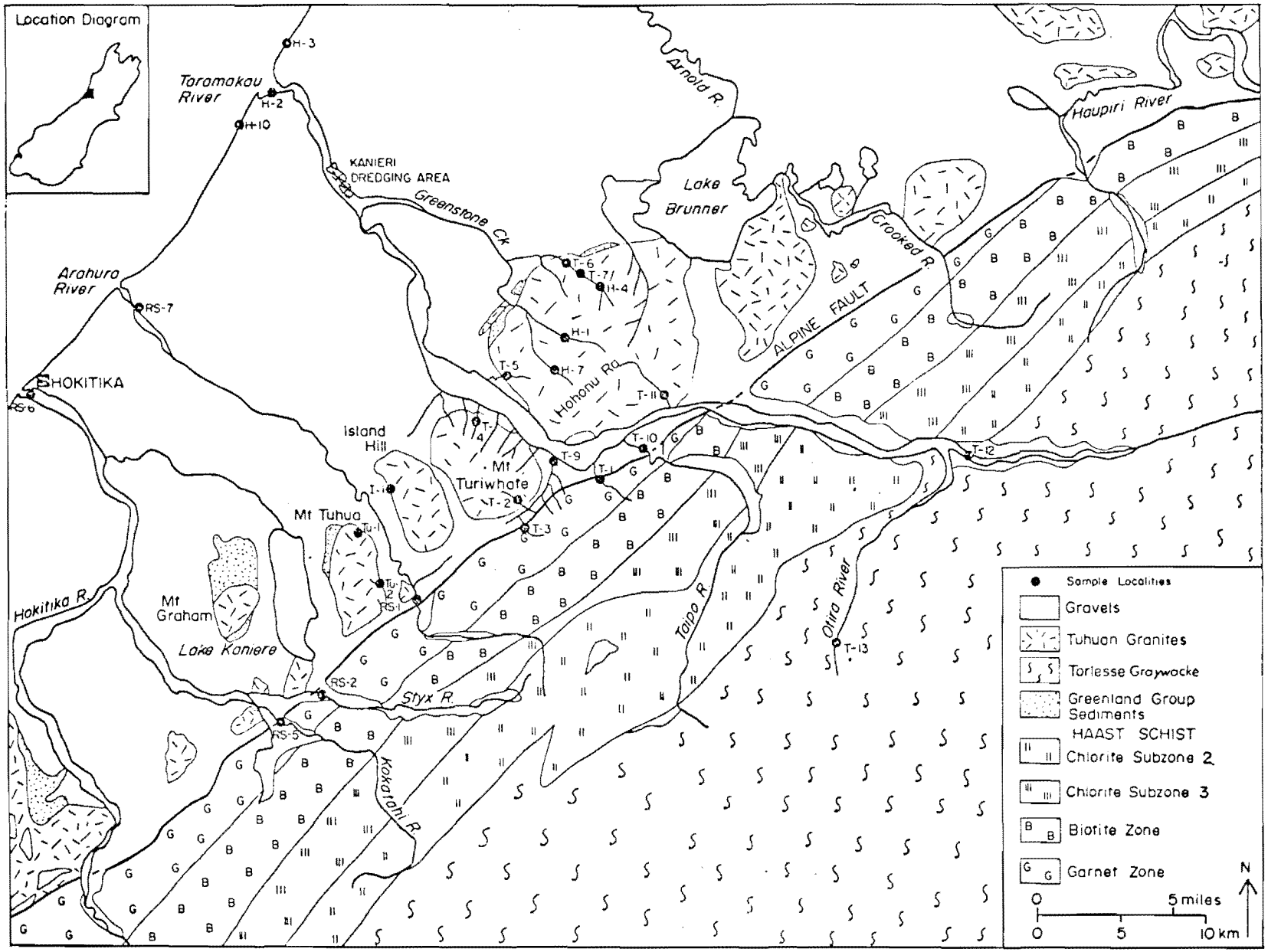
processes. During weathering uranium is released from the source rock and on oxidation to the hexavalent form dissolves in normal surface waters. Most of the uranium is transported to the sea where it is absorbed onto clay and eventually forms extensive, but very low grade uraniferous shale deposits. During its transport to the sea some of the uranium may be precipitated and form relatively high-grade deposits. Precipitation most commonly occurs where the uranium-bearing minerals enter a reducing environment. This causes the hexavalent uranium ions to revert to the insoluble tetravalent form which is deposited as uraninite. Such reducing environments are apparently available where organic materials accumulate in fluvial sand or swamp deposits, or in fractures in igneous rocks over which streams flow."

This is an alternative source for the Taramakau uraninite; instead of being deposited as detrital grains from an unknown granitic source the uraninite may have been precipitated <u>in situ</u> from meteoric waters. Precipitation would require a reducing environment. The pseudo-framboidal pyrite associated with the uraninite indicates that such conditions do exist at the gravel-mudstone interface. Langford states that uranium deposits (i.e., uraninites) of meteoric origin are relatively thorium-free. An XRD powder photograph of the Taramakau uraninite (page 28) suggested that it was stoichiometric UO_2. However, the discrete nature of the uraninite grains does not seem compactable with in-situ deposition (Plate 32).[7]

Several theories on the origin of the "anomalous"

dredge minerals have been presented here. No single one of them provides conclusive evidence but they provide an insight of the many factors involved. In summary the writer concedes that more precise interpretation of the total situation lies well beyond the scope of this study.

FIG. 17 ARAHURA, HOKITIKA AND TARAMAKAU RIVER CATCHMENTS



CHAPTER 11

OTHER MAJOR CATCHMENTS WITHIN THE CENTRAL WESTLAND REGION.

Both the Hokitika and Arahura rivers lie within Hutton's (1950) central Westland region. Samples were taken from both rivers about 20km upstream from their mouths as well as at locations within 1km of the sea (Fig. 17). Two small granitic plutons, Mt. Tuhua and Island Hill, contribute a limited amount of sediment to the Arahura River. Samples were taken from each of these plutons together with rock samples for subsequent XRF analysis and petrographic examination of thin sections (Table 2 , pages 12-14).

Stream sediments from these granitic plutons contain essentially the same heavy mineral suites (Table 11:1) as those of the Taramakau granites (Table 5:1). Overall, both rivers show little difference between their mineral assemblages and those of the lower Taramakau, although in the lower Hokitika River (RS6) typical schist derived pumpellyite is a common constituent. Radioactivity measurements showed count rates which were barely above background for most samples, although as with the Taramakau granites the less magnetic fractions did show counts which were significantly above background levels. Since these samples showed a close correspondence with those of the Taramakau catchment it was decided that establishment of a more detailed sampling pattern within the Arahura and Hokitika catchments was not warranted.

TABLE 11.1

Composition of Magnetic Fractions.

Arahura Catchment.

Sample No	Magnetite	0.2 Amps	0.35 Amps	0.45 Amps	0.75 Amps	1.2 Amps	Rejects
Tu 1	MM	II, H, L*, MM	HH, B, S, P, L*, E*	HH, E, P, L*	S, L, EE, P, D*	SS, FF, LL,	ZZ, S, F, LL
Tu 2	MM	II	HH, I, G*	HH, PP, EE, L, D*, G*	LL, DD, PP, H, Pu, EE	SS, PP, T*, L	ZZ, R, FF, PP, S
I-1	MM	II, MM, H, B	HH, BB, L	EE, P, HH, Cl*, B*	EE, Cl*, P LL	LL, FF, S, P*, A*	ZZ, F, A, L, P*, S*, Q*
RS-1	MM	II, GG, Tr*	BB, GG, I, cc, E*, Tr*	EE, B, Mu, L, C	EE, MuMu, B, L, P*T*	SS, E, R* P*, Mu*	SS, R*, Z*
RS-7	MM	II, BB, G,	B, C, G, E*	B, E, C, LL, Mu, G*	E, BB, Mu, TrTr, S*	SS, L, Mu, B, Tr, R	SS, P*, L*, ZZ, FF,

Hokitika Catchment

Sample No	Magnetite	0.2 Amps	0.35Amps	0.45 Amps	0.75 Amps	1.2 Amps	Rejects
RS 5	MM	II, G, CC	CC, GG, BB, M	CC, B, Mu, E, L	B, E, CC, Tr, Mu	SS, Tr, L, P* MuMu, E*	SS, RR, P, Tr* Z*, Q*, Sc
RS 2	MM	II, G, CC	CC, B, G, MuMu	B, Mu, C, T*, E*	B, Mu, CC, Tr, E	SS, Mu, L Tr, E	SS, P*R*, Z* Q*, Tr*
RS 6	MM	II, BB, GG	GG, B, E	EE, C, H, B, G, Mu*	EE, B, Mu, Tr, Lu, Pu	S, E, Pu, Tr LL, Cl*, P*, R*, Mu	ZZ, S, R*, F

XX = main constituent, > 40%; X = 15-40%; XX = 5 - 15%; X = 1-5%; X* = < 1%; incl. = inclusions present

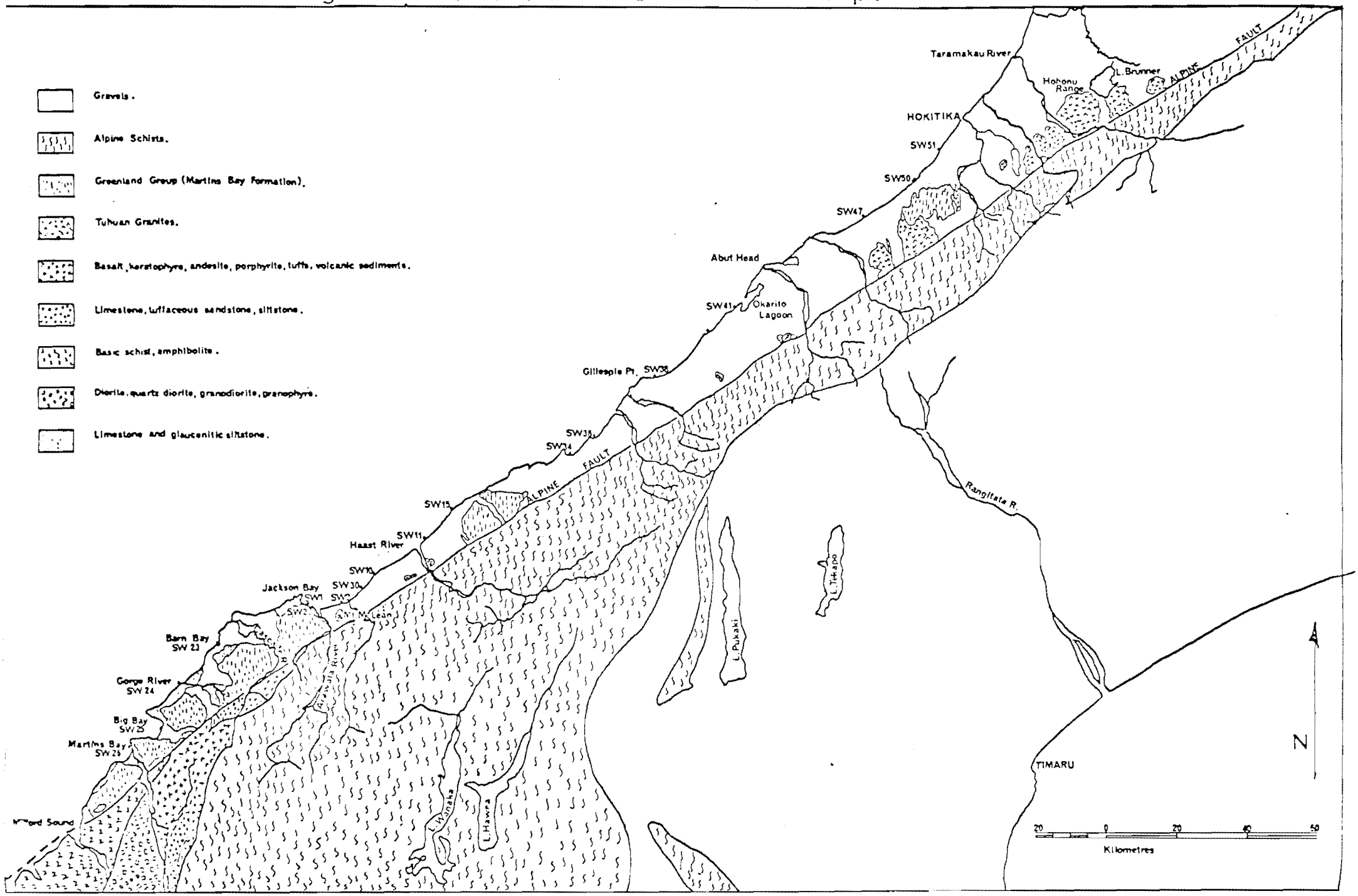
Anatase = A; Apatite (Fluorapatite) = F; Biotite = B; Chlorite = C; Diopside = D; Enstatite = En; Epidote = E; Garnet = G; Hornblende = H; Ilmenite = I; Leucoxene = L; Magnetite = M; Muscovite = Mu; Pyrite = P; Pumpellyite = Pu; Rutile = R; Sphene = S; Scheelite = Sc; Tremolite-Actinolite = Tr; Tourmaline = T; Zircon = Z.

For sample localities refer to Fig. 17 or Appendix Three.

PART II

THE SOUTH WESTLAND BEACHSANDS.

Fig 18 The South Westland Beachsands — Sample Locations.



CHAPTER 12

A BRIEF SURVEY OF BEACHSANDS BETWEEN HOKITIKA AND MILFORD SOUND.

1. Introduction.

A cursory inspection of the geological maps would indicate that beachsands as far southwards as Jackson Bay would be derived almost exclusively from the Alpine schists. The grade of the schists becomes progressively higher towards the south but otherwise no important differences in the detrital mineral suites might be anticipated. However, as discussed in Chapter 1, Hutton (1950) has distinguished a separate mineral province southwards from Ross characterised by the presence of thorite, uranothorite and scheelite. Although subsequent writers have made little reference to Hutton's geographical designation, it seemed appropriate to examine at first hand this situation in relation to the writer's findings further to the South.

From Jackson Bay to Milford Sound where a greater variety of rock-types occurs, especially the ultramafics, the beachsand situation could be expected to be more complicated. Unlike the more northerly regions the coastline is very rugged and beachsand accumulations are rather sparse. For the simple reason that there are only isolated pockets of sand, representative beachsand sampling may lose some of its value in this region.

Eighteen beachsand samples were taken from Ruatapu beach in the north to Martins Bay, in the south at localities

indicated in Fig. 18. In all cases the sand was recovered from the present surface material. It must be emphasised that examination of these samples would relate only to the present conditions and that a complete survey of the total beachsand deposits along this coast would require an extensive drilling programme within both dunes and beaches.

2. Composition of Samples. (Table 12:3).

The overall composition of the beachsands remains essentially constant from Hokitika to the Arawata River (Table 12:3(a)), although the corresponding magnetic response profiles (Fig. 19) indicate that the relative proportions of the constituent minerals vary considerably. Because in most cases the samples are composed entirely of typical schist minerals the few exceptions which are found warrant discussion.

Sample SW30 was collected approximately 2 km north of the granitic pluton Mt. McLean, which outcrops less than 1 km from the beach. The influence of this small pluton (3.2 km^2) is reflected in the magnetic response profile (Fig. 19) of this sample. The proportion of magnetite rises markedly while both granitic epidote and sparse hornblende appear along with the bulk of characteristic schist minerals.

Black, apatite crystals (Plate 35) which were reported as a rare constituent of the Taramakau graywacke minerals (page 47) occurred also in samples SW41 (Okarito Beach) and SW38 (Gillespies Beach). The occurrence of these

elongated, opaque crystals in beachsands suggests that they are rather more persistent than the 'normal' apatite encountered in the Taramakau catchment.

Plate 35 Black Apatite 2ϕ x64

To the south of Jackson Bay there is a marked change in the heavy mineral suites (Table 12:3(b)). Their compositions are sufficiently different to warrant individual discussion

SW1, Jackson Bay.

Pyrite is a major constituent of this sample and its unusual distribution over a wide range of magnetic fractions suggests a variable composition. With its limited persistence it is to be found in the beachsands only because it derives from the widespread quartz veins in the Greenland group rocks which rise steeply from the beach itself.

Zoisite ($Ca_2Al.Al_2O.OH[Si_2O_7][SiO_4]$) which is the iron free member of the Epidote group minerals of general formula (Ca,Fe,Al). $Al_2O.OH.Si_2O_7,SiO_4$ was identified as a minor constituent of this sample. It is of similar appearance to epidote but lacks the distinctive greenish hue.

Plate 36 Zoisite 2ϕ x64

SW23, Barn Bay. The epidote minerals which include clinozoisite and zoisite are the major constituents of this sample. It was somewhat surprising that the relatively soft chlorite occurs on this beach, but the proximity of source rocks may again be the explanation.

SW24, Gorge River. Although the epidote minerals also dominated this sample, the most interesting feature is the occurrence of chromite in the more strongly magnetic fractions. This distinctive black mineral with a brillant

lustre is an accessory which is characteristic of ultrabasic rocks and as such it would seemed to have been derived from the peridotites, dunites and serpentinites of the Red Mountain-Cascade River area.

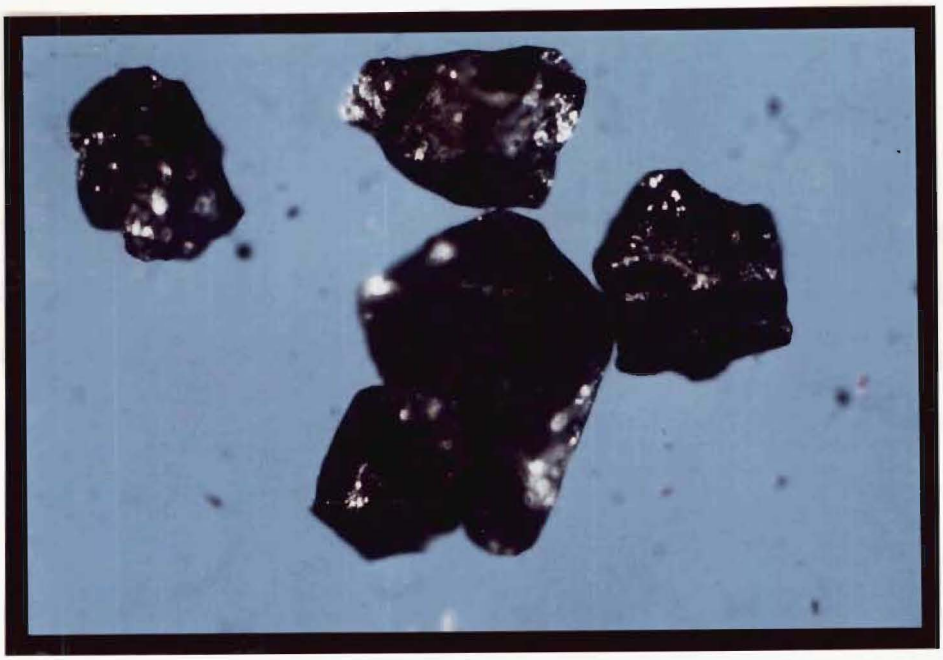


Plate 37 Chromite $FeO.Cr_2O_3$ 2ϕ x64

SW25, Big Bay. Hornblende and epidote minerals make up the bulk of this sample. Those in lesser proportions which include zircon, sphene, tremolite, rutile, garnet and magnetite have probably been derived from the surrounding Martins Bay formation which is described as graywacke, quartz-muscovite schist, pink and green tuff with rare marble lenses (NZGS Sheet 19, Haast, 1st edition).

SW26, Martins Bay. The sample consists mainly of minerals which this study has shown to be widely distributed. It will be seen from Table 12:3 that diopside is the only constituent of the 0.2 amp magnetic fraction. As compared with diopside

found in the Taramakau catchment (Table 5:1 page 37) this species has a higher magnetic response, a feature which suggests that it may be of the iron rich, ferro-augite variety.

3. Radioactivity. (Table 12:4).

Of the eighteen samples examined none showed count rates significantly above background. This is in line with the complete absence of individual radioactive minerals. Nonetheless, in view of Hutton's reports of thorite and uranothorite occurrences at certain localities evidence of radioactive constituents would not have been unexpected. Even the finer fractions from those beachsands (Gillespies Beach SW38, Okarito Beach SW41, Bruce Bay SW34) mentioned specifically by Hutton to contain fine grained thorite and uranothorite, were devoid of radioactivity. This point is discussed in relation to Hutton's work in the following chapter.

4. Discussion.

The present study was designed as a survey of the mineralogical composition of the present beachsands. It has confirmed the writer's expectation that mineralogical content of those beachsands in proximity to the Alpine schist belt is consistent with their almost exclusive derivation from these rocks. From Jackson Bay southwards, where the rocks become more varied there is a corresponding change in the mineral content of the adjacent beachsands.

Weights of Magnetic Fractions

Sample No.	Weight of sample floated	Weight of heavy minerals	Percentage yield	Size fraction selected	Weight of this size fraction	Weight of Magnetite	Weight of 0.2 amps	Weight of 0.35 amps	Weight of 0.45 amps	Weight of 0.75 amps	Weight of 1.2 amps	Weight of Rejects
SW 1	230gm	1.581gm	0.63%	Total unsieved	5.581gm	0.185gm	0.072gm	0.364gm	0.534	0.267gm	0.094gm	0.065gm
SW 2	150	98.290	65.52	3.0ϕ	58.700	49.300	1.592	2.890	1.248	0.720	0.337	2.449
SW10	200	1.007	0.50	Total unsieved	0.961	0.115	0.142	0.291	0.152	0.121	0.029	0.111
SW11	100	94.310	94.31	3.0ϕ	44.200	24.300	11.865	6.316	0.239	0.400	0.278	0.885
SW15	100	5.960	5.96	Total unsieved	5.960	0.155	0.575	2.358	0.912	1.049	0.300	0.611
SW20	200	14.192	7.96	3.0ϕ	10.173	0.450	0.551	2.475	2.674	3.306	0.251	0.368
SW23	250	8.300	3.32	Total unsieved	7.650	0.826	1.091	1.919	1.827	1.524	0.335	0.129
SW24	250	95.830	38.33	2.0ϕ	35.500	1.530	1.243	10.388	13.726	7.640	0.457	0.347
SW25	175	2.854	1.63	Total unsieved	2.854	0.052	0.097	0.688	0.963	0.765	0.100	0.140
SW26	200	0.939	0.47	Total unsieved	0.939	0.003	0.020	0.445	0.000	0.335	0.025	0.111
SW30	200	63.046	31.52	3ϕ	37.946	28.093	2.741	3.043	1.375	0.729	0.316	1.649
SW34	250	198.700	79.48	2ϕ	32.000	0.328	18.493	4.150	3.280	2.000	0.358	3.389
SW36	250	244.900	97.96	2ϕ	80.280	1.085	27.64	50.500	0.377	0.290	0.128	0.260
SW38	400	92.100	23.02	2ϕ	58.730	2.064	6.027	32.000	3.449	6.160	2.167	6.863
SW41	400	54.700	13.67	2ϕ	38.550	0.000	6.450	15.361	4.387	10.976	0.724	0.654
SW47	150	141.680	94.45	3.0ϕ	77.880	0.378	32.90	41.300	0.897	1.000	0.367	1.046
SW50	100	99.700	99.70	3.0ϕ	33.300	0.163	9.473	19.186	0.927	1.379	0.560	1.613
SW51	150	143.360	95.57	3.0ϕ	13.576	0.199	2.578	9.110	0.487	0.414	0.185	0.602

Weight Percentage of Magnetic Fractions of Total Heavy Mineral Weight

Sample No.	Weight of sample	Magnetite	0.2amps	0.35amps	0.45amps	0.75amps	1.2amps	Rejects
SW 1	1.581	11.70	4.55	23.02	33.77	16.88	5.94	4.11
SW 2	58.700	83.98	2.71	4.92	2.12	1.22	0.57	4.17
SW10	0.961	11.96	14.77	30.28	15.81	12.59	3.01	11.55
SW11	44.200	54.97	26.84	14.28	0.54	0.90	0.62	2.00
SW15	5.960	2.60	9.64	39.56	15.30	17.60	5.03	10.25
SW20	10.173	4.42	5.41	24.32	26.28	32.49	2.46	3.61
SW23	7.65	10.80	13.14	14.27	23.89	19.93	4.38	1.69
SW24	35.50	4.30	3.50	29.26	38.66	21.52	1.34	0.97
SW25	2.854	1.82	3.39	24.10	33.74	26.80	3.50	4.90
SW26	0.939	0.31	2.12	47.39	0.00	35.67	2.66	11.82
SW30	37.946	74.03	7.22	8.01	3.62	1.92	0.83	4.34
SW34	32.000	1.02	57.79	12.96	10.25	6.25	1.11	10.59
SW36	80.28	1.35	34.42	62.90	0.46	0.36	0.15	0.32
SW38	58.73	3.60	10.30	54.49	5.88	10.49	3.69	11.69
SW41	38.55	0.00	16.74	39.85	11.38	28.48	1.88	1.70
SW47	77.88	0.49	42.25	53.03	1.16	1.29	0.48	1.35
SW50	33.30	0.49	28.45	57.62	2.79	4.15	1.69	4.85
SW51	34.00	1.50	18.99	67.11	3.59	3.05	1.37	4.44

TABLE 12:3 COMPOSITION OF MAGNETIC FRACTIONS

	SAMPLE NO.	Magnetite	0.2 amps	0.35 amps	0.45 amps	0.75 amps	1.2 amps	Rejects
(a)	SW51	MM	II,GG,	GG,II,	G,B,E.	EE,B,Pu,Mu R',T',H'.	ClCl,S,Pu En,R'.	ZZ,S,R'.L'. QQ.
	SW50	MM	II,GG,	GG,II,	G,B,EE, HH.	EE,B,Pu',En', Mu',	ClCl,S,En, Pu,R,Mu',Tr'.	ZZ,SS,QQ, R'.
	SW47	MM	II,GG	GG,II	EE,B,GG	EE,B,Mu,R'.	ClCl,S,RR, En,Pu.	ZZ,SS,QQ,R'.
	SW41	MM	II,GG,B,C'.	GG,I,C,B.	EE,BB,GG.	EE,BB,Pu.	SS,F,Pu,Cl En.	ZZ,SS,FF,Q.
	SW38	MM	II,GG,B.	GG,I,B,E'.	EE,B,G,c.	EE,B	ClCl,PuPu,Mu, SS.	ZZ,Q,SS, R',F'.
	SW36	MM	II,GG,B'.	GG,I,E'.	GG,B,EE.	BB,E,MuMu, R',Pu'.	RR,Cl,S, Tr,BB.	ZZ,SS,QQ, R'.
	SW34	MM	II,G	GG,I.	BB,G,E.	BB,E,G'.	SS,B,ClCl,E, MuMu,R',T'.	ZZ,Q,S,R'.
	SW30	MM	II,GG	EE,B,GG,H'.	EE(granite & schist),B,T',H'.	EE(granite & schist) B	SS,Cl,L', R',Tr'.	ZZ,SS,Q', R',Hy'.
	SW20	MM	I,B,C,GG	EE,BB,G'.	EE,B,T'.	EE,BB,Tr'.	SS,Cl,Lu,R'.	SS,Z,QQ, R'.
	SW15	MM	II,GG,C.	GG,B,E,C.	EE,B,G'T'.	EE,B.	SS,Pu,EE,R', ClCl.	SS,Z,QQ P'.
	SW11	MM	II,G.	GG,II,E'.	EE,B,G'.	BB,EE,Mu, R'.	ClCl,S,R', Lu',Mu'.	ZZ,S,QQ, R',Hy',Gold'.
	SW10	MM	II,GG,C	G,B,C,E.	EE,B,T'.	EE,B,T'.	SS,Cl,L', Mu'.	ZZ,S,Q,R'
	SW2	MM	II,GG,E,C'.	GG,E,I,B.	EE,BB,G',T'.	EE,B,T'.	ClCl,SS, R'.	ZZ,SS,R', Q.
(b)	SW1	MM	B,P,E,C'.	E,P, C,I.	E, PP,B,C.	PP,E,L,	PP,Mu,Cl.	ZoZo,P,Z, Q.
	SW23	MM	I,B,C,G.	EE,BB,G.	EE,LL.	EE,Tr,B.	ClCl,S,Tr, T'.	ZoZo,SS,QQ, L,ZZ.
	SW24	MM	CC, B',Cr'.	CC,Cr,B'.	CC,Cr'.	EE,Tr,B.	ZoZo,TrTr,SS	ZoZo,ZZ,Q L.
	SW25	MM	H,EE,BB,G'.	HH,B,E,G.	EE,H	EE,Tr,H,T'.	ClCl,E,Mu,Tr.	ZoZo,ZZ,L, S,R',TrTr.
	SW26	MM	DD,	BB,C	No Sample	E,BB,CC,T,D.	S,Mu,Cl,L, T'.	ZoZo,SS,ZZ,R'. P',L',TrTr.

Apatite (Fluorapatite) = F; Biotite = B; Cassiterite = Ca; Chlorite = C; Chromite = Cr; Clinozoisite = Cl; Diopside = D; Enstatite = En, Epidote = E; Garnet = G; Gold = Gold; Hornblende = H; Hyacinth = Hy; Ilmenite = I; Magnetite = M; Monazite = Mo; Muscovite = Mu; Pyrite = P Pumpellyite = Pu; Quartz = Q; Rutile = R; Sphene = S; Tremolite-Actinolite = Tr; Tourmaline = T; Zircon = Z; Zoisite = Zo.

XX = main constituent, > 40%; X = 15-40%; XX = 5 - 15%; X = 1 - 5%; X* = < 1%. incl. = inclusions present.

TABLE 12:4

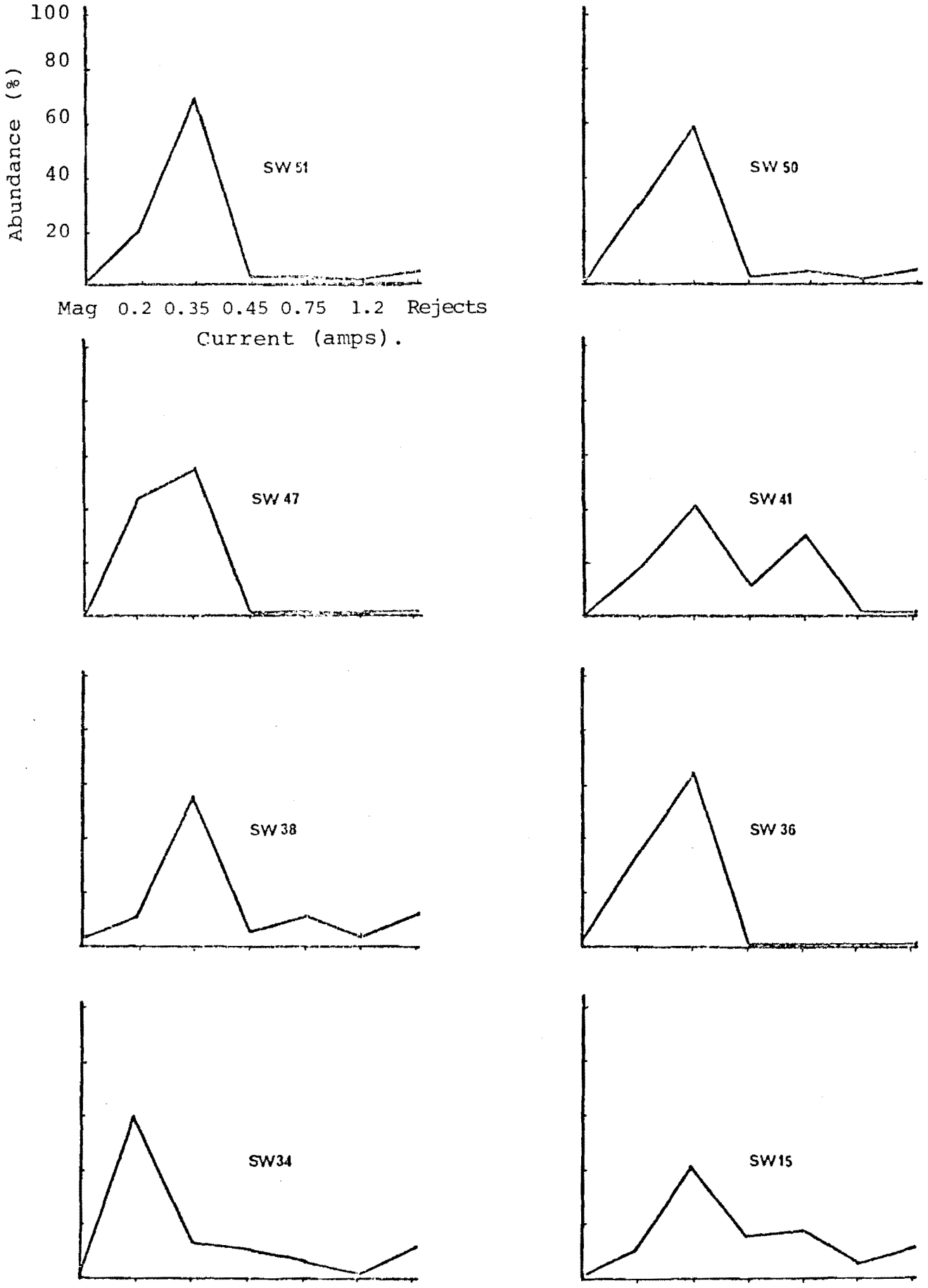
Units = Counts Radioactivity T = 1.2 minutes

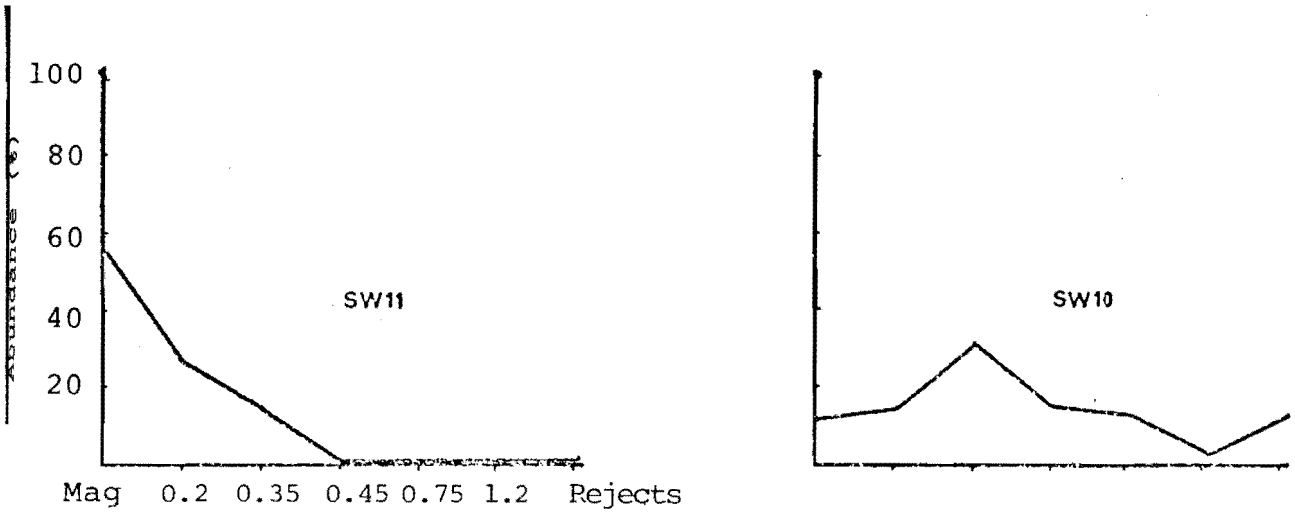
Sample No.	Background	Magnetite	0.2amps	0.35 amps	o.45amps	0.75amps	1.2amps	No.Rejects
SW 1	18	23	18	12	15	12	7	15
SW 2	17	19	18	17	14	13	18	18
SW10	9	16	14	21	13	13	14	20
SW11	13	14	20	11	18	23	37	28
SW15	12	13	10	17	14	21	13	14
SW20	14	11	21	14	18	23	13	13
SW23	17	11	14	18	21	12	17	17
SW24	12	17	-	14	13	16	18	6
SW25	16	14	20	16	15	17	15	21
SW26	11	13	9	16	-	16	17	13
SW30	14	14	14	19	22	10	10	11
SW34	14	16	19	16	13	24	18	14
SW36	13	12	14	10	16	12	16	25
SW38	12	17	22	16	20	24	12	20
SW41	16	-	12	13	8	12	17	9
SW47	13	16	9	9	15	14	18	23
SW50	14	16	13	15	11	10	14	9
SW51	18	13	14	11	17	13	12	23

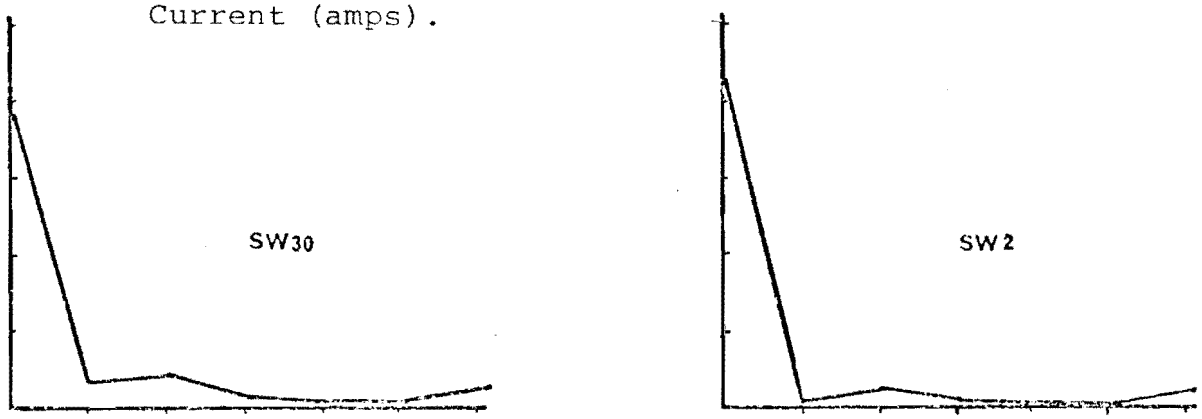
Fig. 19

Magnetic Response Profiles - South Westland Beaches.

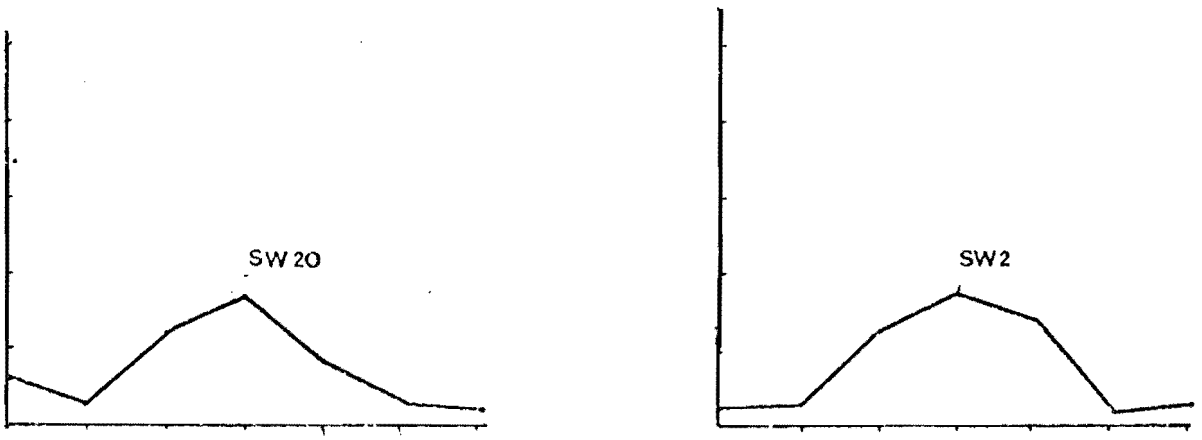
(a) Hokitika - Jackson Bay.

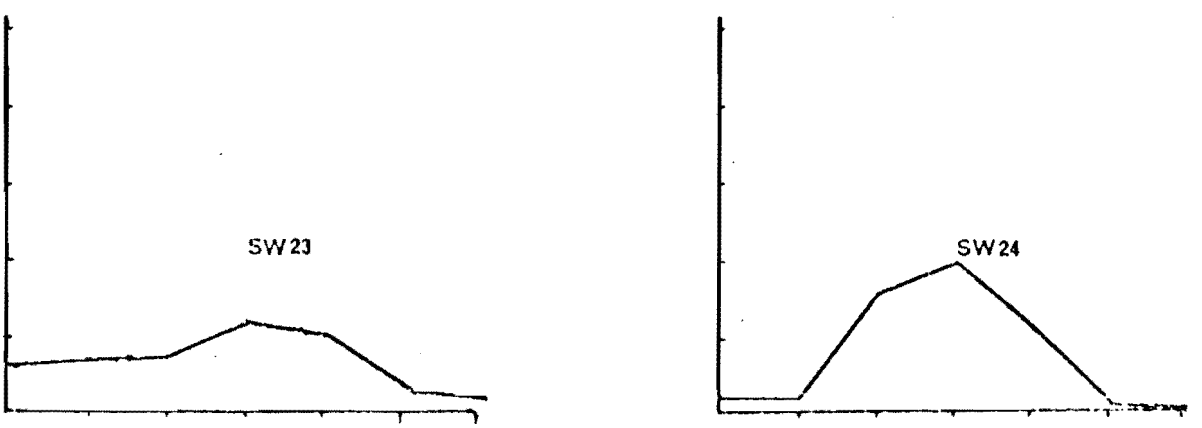


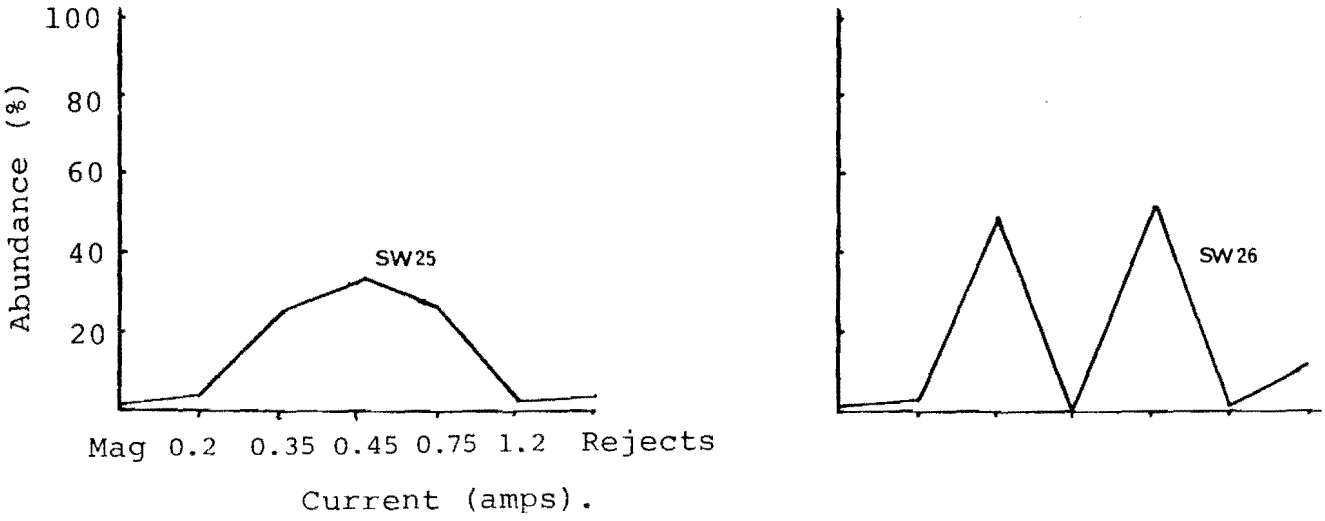




Jackson Bay - Milford Sound.






100
80
60
40
20
Abundance (%)
SW25
SW26
Mag 0.2 0.35 0.45 0.75 1.2 Rejects
Current (amps).

CHAPTER 13

CONCLUDING REMARKS

The present work is based on an approach differing from those made in previous studies. In so far as it does not emphasise detailed petrology or small localised occurrences it is possible that a few minerals of very minor occurrence may have been overlooked. At the same time, both the sampling patterns and laboratory procedures were such that any significant accession to a sediment or beachsand accumulation could not escape identification. In fact several new occurrences have been found; the minerals uraninite, thorite, monazite, cassiterite, scheelite and pseudo-framboidal pyrite have not been previously reported from the Taramakau region.

Mason (1952) has presented a detailed account of the minerals distributed throughout the Alpine schists and Torlesse Graywackes. One or two minerals which he reported from these rocks were not encountered in the present work, (e.g., tourmaline from within the Torlesse graywackes and argillites). However, the sampling plans were usually designed to provide an extensive rather than a detailed local coverage. Consequently less common minerals could have been overlooked although it can fairly be stated that any detrital tourmaline within the Torlesse graywackes in this area must at the most be very sparsely distributed.

A careful comparison of sediments from granites, schists and graywackes in conjunction with information on persistence characteristics has enabled the relative contributions of each rock type to the beachsand accumulate to be assessed for each mineral. Attention has been drawn to the significance of magnetic response profiles (page 84) as evidence of the origin of a total accumulate.

For the most part the results relate only to present conditions. So far as any deliberate mineral exploration work is concerned this is a serious deficiency, as witnessed by the presence of a distinctive, older suite of minerals which happens to be just within reach of the Kanieri dredge. Several factors could have produced considerable changes in erosional patterns during the Pleistocene and even the Quaternary periods. There has been recent uplift on the eastern side of the Alpine fault and yet also on the western side the high-standing granites show very young landforms. Patterns of erosion and accumulation will have been disrupted from time to time and within more local contexts directions of drainage may have been modified, so that for example a more southerly outflow of the Grey River towards the present Taramakau catchment may have occurred (page 99).

That the present field work has revealed one buried suite of minerals (lying on top of a sedimentary interface) emphasises the importance of bore-holes in areas where depositional concentration of heavies may be expected. In the present area of study it is possible that some of

the buried minerals of the lower Taramakau have been transported down the course of the Greenstone River, from what might be perhaps only a now barren remnant of a once more extensive Hohonu hydrothermal mineralisation (Figs.1 and 2). Likewise the buried sediments of the Grey Valley may contain detritals from both the Paparoa range and the granites to the east, which between them continue to provide gold, cassiterite and monazite.

Hutton (1950) subdivided the West Coast of the South Island into three distinct mineral provinces,

(i) the southern to central Westland area extending from Bruce Bay northwards to about Saltwater Creek and Hari Hari, in which he regards zircon-scheelite-thorite-uranothorite assemblages as characteristic;

(ii) the Ross-Lake Mahinapau-Kokatahi-Arahura area, "with extensions north towards Kumara", characterised by a relatively simple garnet-zircon-epidote (clinozoisite)-hornblende assemblage;

(iii) the Grey River basin and the Cape Foulwind-Westport coastal plain to 'southern Nelson', which is characterised principally by a zircon-hyacinth-monazite-xenotime-tantalian cassiterite assemblage.

The occurrence of tantalian cassiterite, monazite, scheelite and thorite within the Taramakau catchment has shown that these mineral provinces cannot be adhered to rigidly. Furthermore the evidence cited by Hutton does not warrant his subdivision of Westland into such provinces.

The sparse thorite, uranothorite and scheelite which he reported from the area south of Ross are not specific to that region. It would appear from Hutton's paper that the thorites were to be found only in small isolated sub-surface deposits of fine-grained 4.0ϕ material which is not characteristic of generally much coarser beachsand. Nor was the writer able to find thorites in present day surface deposits, but on the other hand thorites have now been identified as minor constituents of the deeper (20m) deposits reached by the Kanieri Dredge. Also, in the Taramakau area scheelite occurs sparsely in the present day river sediments.

It is hardly surprising that, on the basis of detrital minerals, no distinction can be made between the northern (Taramakau) and more southerly regions of Westland. Apart from longshore accession from the south,[8] detrital deposits over the whole area are largely derived from the Alpine schists, with the granites (wherever they occur) making a relatively small additional contribution.

Relationships between the sediments from the Grey Valley (Hutton's northern region) and the Taramakau area have not been examined in the present work. However the monazite and tantalum-containing cassiterite considered by Hutton to be characteristic of that more northern region, do occur also in the buried Taramakau gravels reached by the dredge. Thus the minerals taken by Hutton as characterising his northern and southern provinces occur also in the Taramakau region, and of all

the minerals in this central area only uraninite has not so far been identified elsewhere as detrital grains.

Nicholson (1955) concluded from his work that the only possibility of obtaining usable supplies of uranium and thorium minerals in New Zealand was from the concentrates of the dredges operating at various places on the West Coast of the South Island. He examined concentrates from several dredges then operating, including a sample from the Arahura gold dredge working in the Arahura River-Kawaka Creek area. He reported that concentrate from this dredge contained a percentage value for radioactive content expressed as "equivalent U_3O_8 percent", which was in one case similar to the uranium values obtained from Taramakau dredge concentrates.* Apart from this exceptional case most other samples showed levels of radioactivity (expressed as "equivalent U_3O_8 percent") corresponding only to about one tenth of the present uranium values. In no instance was the primary uranium mineral uraninite reported.

* It should be remarked that the percentages quoted by Nicholson appear to have been based entirely on measurements of radioactivity. This activity would be contributed by both uranium and thorium. In the absence of specific uranium minerals the average crustal abundance ratio, uranium:thorium is close to 1:4 and the half lives of the abundant isotopes U^{238} and Th^{232} are in the approximate ratio 1:2. Therefore, assuming each isotope produced radiation of similar total intensity from its decay chain, about one half of the activity from Nicholson's samples would have come from uranium and the remainder from thorium.

Both Hutton and Nicholson reported (as indeed the present writer has found), that the radioactivity follows the finer size fractions and that the dredges were very inefficient at retaining this fine material. In fact, Nicholson found that the amount of radioactive material discarded in the dredge tailings at least equalled the amount retained by the jigs. Among Nicholson's conclusions and recommendations was the following remark, "Where some other reason exists for the exploitation of a deposit such as dredging for gold and other valuable minerals, e.g., cassiterite, zircon, rutile, ilmenite, it should be possible in certain areas to produce small quantities of radioactive minerals as a biproduct".

* * * *

With the completion of the work in this thesis it is possible to make some retrospective assessment of the value and limitations of the approach which has been used. No strictly comparable academic study seems to have been made within the New Zealand area, although from information gleaned by the writer it became evident that some kind of survey monitoring of surface deposits throughout Westland has been made by mining companies (probably by way of chemical analysis for metalliferous content).

An approach based on complete mineralogical analysis is time-consuming but provides information of a more fundamental kind with both academic and possible practical implications. The occurrence of the minerals can be related to the petrology of the contributing rocks, and the influence of mineral persistence and local geography become apparent. For any

element both characteristic and carrier minerals come under examination and information can at the same time be obtained on particle-size distribution.

The systematic nature of the approach means that, at least in principle, nothing can be overlooked. The discovery of the zone of hydrothermal alteration in the Hohonu range (see page 8) was the result of systematic field coverage and the discovery of the cassiterite-monazite-uraninite suite in dredge concentrate was made through systematic laboratory examination of samples.

On the other hand an essentially academic study of this kind is limited to examination of mobile surface deposits. The experience from this study would indicate that climatic changes and recent tectonic movement may have considerably altered depositional patterns within the recent past, so that where surface indications are favourable there can be a good case for bore-hole sampling. In retrospect it seems unfortunate that, perhaps through inadequate background information at the time, no interest was taken in the detrital heavy minerals excavated by the Kanieri dredge when it was working up the Greenstone tributary of the Taramakau some ten years ago (see Fig. 1 page 6).

It has to be remarked too, that besides the obvious limitations imposed by the field resources available to a student, the utility of the approach varies with geography. It was less easily developed south of Jackson Bay than in the north, both because of difficulties of access into the hinterland and because there were no continuous beachsand accumulations in that area. Nevertheless it has been

demonstrated that, in addition to its academic aspects, this kind of work can contribute in a distinctive way to a survey of mineral resources.

APPENDIX 1

Standard Mesh Dimensions.

Size class*	Phi(ϕ)	Microns	Mesh No.
very coarse sand	-1.0	2000	10
coarse sand	0.0	1000	18
medium sand	1.0	500	35
fine sand	2.0	250	60
very fine sand	3.0	125	120
	4.0	62.5	230

* after Wentworth (1922).

The precise definitions of the various phi units as quoted in this study are as follows:-

2.0ϕ refers to all material which has passed through the 1.0ϕ (500μ) mesh but has been retained by the 2.0ϕ (250μ) mesh, i.e., $250\mu \leqslant x \leqslant 500\mu$ (x = grain size). Similarly for all other mesh sizes.

<4.0ϕ refers to all material which has passed through a 4.0ϕ (62.5) mesh, i.e. $x < 62.5\mu$.

>2.0ϕ refers to all material coarser than 2.0ϕ(250μ) including 1.0ϕ and 0.0ϕ fractions, i.e., $x > 250\mu$.

APPENDIX 2

Principles of isomorphous replacement. The geochemistry of zircon.

Since minerals have generally crystallised slowly under conditions that can provide a wide variety of ions at greater or lesser concentrations, isomorphous replacement is a common feature. A particular species has its own characteristic crystal structure and distinctive properties, but unlike most pure chemical compounds it usually shows variations in composition, often slight, but occasionally large due to isomorphous substitution. Such substitution can occur wherever a substituting ion is of suitable size to enable it to occupy a replacement position and at the same time is able to enter the lattice without upsetting the charge balance. The ions Mg^{2+} and Fe^{2+} can readily replace one another, likewise the ions Mn^{2+}, Co^{2+} and Ni^{2+} can replace Fe^{2+} and the trivalent ions Al^{3+}, Fe^{3+} and Mn^{3+} can substitute one another.

Ions of different charge may enter a lattice provided some compensating effect can occur. Thus Ca^{2+} can replace Na^{2+} in the plagioclase series, provided there is simultaneous replacement of Si^{4+} by Al^{3+} at SiO_4^{4-} tetrahedral centres. Y^{3+} (0.89Å) can replace Ca^{2+} (1.18Å) in the fluorite lattice through simultaneous replacement of F^- by O^{2-}.

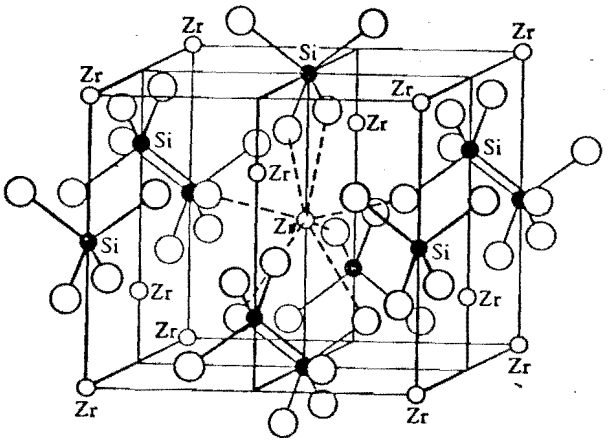


Fig. 20 The structure of Zircon. The eight bonds from each Zirconium atom to the neighbouring oxygens are shown only at the centre of the figure (Bragg 1937).

Zircon is notable as a carrier for uranium, thorium and rare earths. Its role as a carrier mineral requires some comment. The Zr^{4+} ion in zircon is in 8 coordination. This is unexpected in so far as $r(Zr^{4+}):r(O^{2-})=0.62$, well below the 0.73 theoretical lower limit for eight-coordination. However the ion has four nearest neighbours at 2.15Å, with the remaining four oxygens at 2.29Å. The lattice is highly effective in accommodating Hf^{4+} (0.86Å) and still efficient in accommodating Y^{3+} and M^{3+}_{RE}. It seems well established that the isomorphous replacement of Zr^{4+} by these M^{3+} ions is accompanied by simultaneous replacement of SiO_4^{4-} by PO_4^{3-} (witness the isostructural relationship of xenotime, YPO_4 and zircon).

The capacity of the zircon lattice to accommodate cations larger than Zr^{4+} is quite striking, and raises

the question as to whether the coordinated SiO_4^{4-} ions can rotate a little so as to increase the shorter M^{n+}.....O distances if the demand arises. Nonetheless it is significant that zircon is much better at accommodating the heavier rather than the lighter rare earths, since the heavier members have smaller ionic radii due to the lanthanide contraction effect. Therefore while zircon usually contains detectable amounts of thorium and uranium (Th^{4+}, 1.10Å and U^{4+}, 1.05Å), it is ytterbium (Yb^{3+}, 1.00Å) - the heaviest rare earth element of even atomic number (70) which is particularly concentrated in this mineral.

APPENDIX 3

Sample Localities

Taramakau Catchment

T-13	Upper Otira River	Fig. 1
T-12	Taramakau River	
T-10	Taipo River	"
T-9	Lower Wainihini River	"
T-3	Lynch Creek	"
T-1	Griffin Stream	"
T-11	Ruberslaw Creek	"
T-7	Little Hohonu River	"
T-6	" " "	"
T-5	Clear Creek	"
T-4	Mt. Turiwhate	"
T-2	Quartz Creek	"
H-7	Right branch of Greenstone River	"
H-4	Little Hohonu River	"
H-1	French Creek	"
H-10	Beach south of Taramakau River mouth	"
H-3	" north " " " "	"
H-2	Taramakau River mouth	"
KD(a)	Kanieri dredge concentrate	"
KD(b)	" " "	"

Arahura and Hokitika Catchments.

Tu 1	Johnson Creek, Mt. Tuhua	Fig. 17
Tu 2	Composite sample, Mt. Tuhua	"
I-1	Island Hill	"

RS-1	Arahura River sample, Milltown Bridge	Fig. 17
RS-7	Lower Arahura River at rail/road bridge	"
RS-5	Kokatahi River	"
RS-2	Lower Styx River	"
RS-6	Hokitika River mouth	"

South Westland beachsands

SW1	Jacksons Bay	Fig 18
SW2	Mussel Point	"
SW10	Haast Beach	"
SW11	North of Haast River mouth	"
SW15	Adiantum Bluff	"
SW20	Niels Beach	"
SW23	Barn Bay	"
SW24	Gorge River	"
SW25	Big Bay	"
SW26	Martins Bay	"
SW30	Carters Mill	"
SW34	Bruce Bay	"
SW36	Hunts Beach	"
SW38	Gillespies Beach	"
SW41	Okarito Beach	"
SW47	Greens Beach	"
SW50	Ross Beach	"
SW51	Ruatapu Beach	"

NOTATIONS

CHAPTER 3.

(1) The settings for the Franz Isodymamic Separator have been suggested by Baker (1962) pp87-88. Here he refers to the results of the magnetic separations carried out on Californian beachsands by Hutton (1952).

CHAPTER 7.

(2) By way of comparison 30% of known uranium reserves in the United States consist of ores containing 0.20 - 0.25% U_3O_8 (2-3 kilos/ton). The ore grade of the Mary Kathleen field, South Australia, averaged 0.18% U_3O_8, while the Blind River deposit, Western Ontario, runs at 0.08 - 0.11% U_3O_8 (Encyclopedia of Chemical Technology, Vol.21).

CHAPTER 8.

(3) It is possible that a considerable proportion of the characteristically fine and flaky, lighter minerals in the sediments from the schists has not been allowed to settle and that selective sedimentation has already concentrated the heavy minerals. This factor would not of course affect the relative heavy mineral contributions of schist and granite but it would effect arguments on the relative rates of weathering of the two rock types.

CHAPTER 9.

(4) Baker (1962) states that persistence of heavy minerals is largely due to:-

(1) Their resistance to dissolution by natural chemical processes.

(2) Their physical stability under severe conditions involving impact and abrasion during transportation by gravitation, wind currents, streams and rivers, ocean tides and currents, and glaciers.

(3) Their ability to withstand reactions set up during diagenesis and any subsequent intrastratal reactions from circulating solutions.

CHAPTER 10.

(5) Personal communication, Dr. G. Jenkins, Department of Geology, University of Canterbury, June, 1977.

(6) The existence of these black-sand leads is known also to Dr. Suggate, Director of Geological Survey, Wellington, who suggests that they may be buried stream channels from a previously southward flowing Grey River. (Personal communication, August, 1977).

(7) Subsequent electron microprobe analysis has shown individual uraninite grains to contain 2-5% thorium.

CHAPTER 13.

(8) Furkert (1947) has estimated that every year four to five million cubic yards of sand are moved northwards past Westport Harbour by longshore drift.

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